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1 APPARATUS AND METHOD FOR OBTAINING 3D IMAGES

2

3 The present invention relates to apparatus and a method  
4 for creating a three dimensional image, and  
5 particularly, but not exclusively, to apparatus and a  
6 method for creating a three dimensional image for use  
7 in surveying.

8

9 Conventional survey equipment typically measures the  
10 distance, bearing and inclination angle to a target  
11 (such as a tree, electricity pylon or the like) or a  
12 target area, with reference to the position of a user.  
13 While this information is useful, it would be  
14 advantageous to create a three-dimensional (3D) image  
15 of the target and/or target area.

16

17 In addition, conventional sighting devices which are  
18 used to select a target to be surveyed often result in  
19 false surveys being made as the target is often not  
20 correctly identified.

21

22 There are a number of conventional techniques which are  
23 capable of generating a three-dimensional (3D) image  
24 from photographs. One such technique is  
25 stereophotography (SP). SP uses two simultaneous

1 images taken by two cameras positioned at fixed points.  
2 The two fixed points are precisely spaced apart along a  
3 baseline distance.  
4

5 However, this conventional technique has a number of  
6 associated disadvantages. Firstly, the pictures are  
7 not direct to digital, which creates difficulties in  
8 manipulating the images after they have been taken.  
9 The images typically require to be ortho-corrected and  
10 the method itself is generally slow and can be  
11 expensive due to the precision cameras required.  
12

13 According to a first aspect of the present invention  
14 there is provided an apparatus comprising an imaging  
15 device, a range finder, and a processor capable of  
16 receiving and processing image and range signals to  
17 construct a three-dimensional image from said signals.  
18

19 According to a second aspect of the present invention  
20 there is provided a method of generating a three-  
21 dimensional image of a target area, the method  
22 comprising the steps of providing an imaging device,  
23 providing a range finder, operating the imaging device  
24 to provide an image of the target area, and  
25 subsequently measuring the distance to each of a  
26 plurality of points by scanning the range finder at  
27 preset intervals relating to the points.  
28

29 The imaging device is preferably a camera, typically a  
30 digital video camera, and preferably a charge-coupled  
31 device (CCD) video camera. Alternatively, the camera  
32 may comprise a digital camera. The camera is  
33 preferably capable of zoom functions. This allows  
34 targets which may be some distance from the apparatus  
35 to be viewed more accurately and/or remotely.  
36

1 The apparatus typically includes a display device to  
2 allow a user to view a target area using the imaging  
3 device. The display device typically comprises a VGA  
4 eyepiece monitor, such as a liquid-crystal display  
5 (LCD) or flat panel display. The display device may  
6 alternatively comprise a VGA monitor. This offers the  
7 advantage that an image of the target may be viewed by  
8 the user to ensure that the correct target has been  
9 selected. Also, the apparatus may be operated remotely  
10 using the camera to view the target area.

11  
12 The apparatus preferably includes a pan and tilt unit  
13 for panning and tilting of the range finder and/or  
14 camera. The pan and tilt unit typically comprises a  
15 first motor for panning of the range finder and/or  
16 camera, and a second motor for tilting of the range  
17 finder and/or camera. The pan and tilt unit typically  
18 includes first and second digital encoders for  
19 measuring the angles of pan and tilt respectively. The  
20 first and second motors are typically controlled by the  
21 processor. The outputs of the first and second  
22 encoders is typically fed to the processor. This  
23 provides a feedback loop wherein the motors are  
24 operated to pan and tilt the range finder and/or camera  
25 through the generated horizontal and vertical angles.  
26 The encoders may then be used to check the angles to  
27 ensure that the range finder and/or camera were panned  
28 and tilted through the correct angles.

29  
30 The image is preferably digitised, wherein the image  
31 comprises a plurality of pixels. Optionally, the image  
32 may be a captured image. The target is typically  
33 selected by selecting a plurality of pixels around the  
34 target, using, for example, a mouse pointer. This  
35 produces x and y coordinates for the target pixels and  
36 defines a target area eg a building or a part thereof.

1  
2  
3 Typically, the range finder is preferably a laser range  
4 finder. Preferably, the laser range finder is bore-  
5 sighted with the camera. This, in conjunction with the  
6 eyepiece monitor used to identify the target area,  
7 offers the advantage that the user can be sure that the  
8 target area he has selected will be captured by the  
9 camera. In addition, any subsequent calculations made  
10 by the processor do not require an offset between the  
11 camera and the range finder to be considered.  
12

13 Preferably, the apparatus includes a compass and an  
14 inclinometer and/or gyroscope. These allow the bearing  
15 and angle of inclination to the target to be measured.  
16 These are preferably digitised to provide data to the  
17 processor.  
18

19 Optionally, the apparatus further includes a position  
20 fixing system for identifying the geographical position  
21 of the apparatus. The position fixing system is  
22 preferably a Global Positioning System (GPS) which  
23 typically includes a Differential Global Positioning  
24 System (DGPS). This provides the advantage that the  
25 approximate position of the user can be recorded (and  
26 thus the position of the target using the measurements  
27 from the range finder and compass, where used.  
28 Preferably, the GPS/DGPS facilitates the time of the  
29 survey to be recorded.  
30

31 The apparatus is typically mounted on a mounting  
32 device. The mounting device typically comprises  
33 headgear which may be worn on the head of a user. The  
34 headgear typically comprises a hard-hat type helmet.  
35 Alternatively, the apparatus may be located within a  
36 housing. The housing is typically a hand-held device.

1     Optionally, the mounting device may be a tripod stand  
2     or a platform which forms part of an elevation system,  
3     wherein the apparatus is elevated to allow larger areas  
4     to be surveyed.

5  
6     Optionally, the apparatus may be operated by remote  
7     control.

8  
9     The compass is preferably a digital fluxgate compass.

10  
11    The apparatus is typically controlled by an input  
12    device. The input device is typically used to activate  
13    the apparatus, and may be a keyboard, keypad, penpad or  
14    the like. Typically, the input device facilitates  
15    operation of a particular function of the apparatus.  
16    The input device is typically interfaced to the  
17    processor via a standard keyboard input.

18  
19    The GPS/DGPS is preferably integrally moulded within  
20    the helmet.

21    The method typically includes the additional step of  
22    selecting the target area to be surveyed using the  
23    imaging device.

24  
25    The method typically includes any one, some or all of  
26    the further steps of

27       obtaining a focal length of the camera;  
28       obtaining a field of view of the camera;  
29       calculating the principal distance of the camera;  
30       obtaining the horizontal offset and vertical  
31    offset between an axis of the camera and an axis of the  
32    laser;  
33       calculating the horizontal and vertical offsets in  
34    terms of pixels;  
35       calculating the difference between the horizontal  
36    and vertical offsets in terms of pixel and the x and y

1 coordinates of the target pixel; and  
2 calculating the horizontal and vertical angles.

3  
4 Optionally, the method typically includes one, some or  
5 all of the further steps of  
6 instructing the pan and tilt unit to pan and tilt  
7 the range finder and/or camera through the vertical and  
8 horizontal angles;  
9 measuring the horizontal and vertical angles using  
10 the encoders;  
11 verifying that the angles through which the range  
12 finder and/or camera are moved is correct;  
13 obtaining horizontal and/or vertical correction  
14 angles by subtracting the measured horizontal and  
15 vertical angles from the calculated horizontal and  
16 vertical angles;  
17 adjusting the pan and tilt of the range finder  
18 and/or camera if necessary; and  
19 activating the range finder to obtain the range to  
20 the target.

21  
22 Preferably, the method includes the additional step of  
23 correlating the position of the pixels in the digital  
24 picture with the measured distance to each pixel. This  
25 generates a set of x, y and z co-ordinates for all of  
26 the pixel points which may be used to generate a three  
27 dimensional image of the target area.

28  
29 Embodiments of the present invention shall now be  
30 described, by way of example only, with reference to  
31 the accompanying drawings in which:-

32 Fig. 1 is a schematic representation of an image  
33 capture and laser transmitter and receiver unit in  
34 accordance with, and for use with, the present  
35 invention;

36 Fig. 2 shows schematically a first embodiment of



1        an apparatus;  
2        Fig. 3 shows an exploded view of the apparatus of  
3        Fig. 2 in more detail;  
4        Fig. 4 shows a simplified schematic illustration  
5        of a digital encoder;  
6        Fig. 5 schematically shows the apparatus of Figs 2  
7        and 3 in use;  
8        Fig. 6 is a schematic representation of the  
9        display produced on a computer screen of a freeze  
10       frame image produced by a digital camera;  
11       Fig. 7 is a simplified schematic diagram of inside  
12       a digital camera;  
13       Fig. 8 is a simplified diagram illustrating how a  
14       principal distance (PD) may be calculated;  
15       Fig. 9 is a simplified diagram illustrating the  
16       offset between the laser and the camera in use;  
17       Fig. 10 is a schematic representation illustrating  
18       a horizontal offset  $H_{offset}$  outwith the camera;  
19       Fig. 11 is a schematic representation illustrating  
20       a horizontal distance  $l_x$  in terms of pixels,  
21       corresponding to  $H_{offset}$ , within the camera;  
22       Fig. 12 is a simplified diagram of a freeze frame  
23       image showing an object;  
24       Fig. 13 is a schematic representation illustrating  
25       the relationship between a horizontal distance  $d_x$ ,  
26       a principal distance PD and an angle  $\theta$ ;  
27       Fig. 14 is a simplified diagram illustrating the  
28       principle of calculating pixel x and y co-  
29       ordinates from horizontal and vertical angles of  
30       and range to the pixel;  
31       Fig. 15 is a simplified diagram illustrating the  
32       relationship between horizontal and vertical  
33       angles of and range to the pixel and three  
34       dimensional co-ordinates of the pixel;  
35       Fig. 16 is a print of the triangular framework  
36       used to recreate a 3D image of a bitmap

1 photograph;  
2 Fig. 17 shows a print of a 3D image which used a  
3 bitmap photograph superimposed on the framework of  
4 Fig. 16;  
5 Fig. 18 is a representation of an alternative  
6 mounting device for the apparatus according to a  
7 first aspect of the present invention;  
8 Fig. 19a is a schematic representation of a  
9 vehicle provided with an elevating arm and  
10 apparatus showing the position of the apparatus  
11 when the vehicle is moving;  
12 Fig. 19b is a schematic representation of the  
13 vehicle of Fig. 19a with the apparatus deployed on  
14 the arm;  
15 Fig. 19c is a schematic representation of the  
16 vehicle of Figs 19a and 19b on a slope with the  
17 apparatus deployed on the arm;  
18 Figs 20a and 20b are respective rear and side  
19 views of the apparatus deployed on the arm;  
20 Figs 21a and 21b are respective side and plan  
21 elevations of the vehicle of Figs 15a to 15c  
22 illustrating the apparatus being used to profile  
23 the ground in front of the vehicle;  
24 Fig. 22 is a schematic view of a second embodiment  
25 of a mounting device;  
26 Figs 23 to 27 show a hand-held housing for the  
27 apparatus according to a first aspect of the  
28 present invention; and  
29 Figs 28 to 30 show the hand-held housing of Figs  
30 23 to 27 in use.  
31  
32 Referring to the drawings, Fig. 1 shows a schematic  
33 representation of an image capture and laser  
34 transmitter and receiver unit 10 which forms part of  
35 the apparatus in accordance with a first aspect of the  
36 present invention. Unit 10 includes a laser 12 (which

1 typically forms part of a laser range finder), where  
2 the laser 12 generates a beam of laser light 14. The  
3 laser 12 is typically an invisible, eyesafe, gallium  
4 arsenide (GaAs) diode laser which emits a beam  
5 typically in the infra-red (ie invisible) spectrum.  
6 The laser 12 is typically externally triggered and is  
7 typically capable of measuring distances up to, or in  
8 excess of, 1000 metres (1 km). It should be noted that  
9 any suitable type of laser may be used.

10

11 The beam 14 is reflected by a part-silvered prism 16 in  
12 a first direction substantially perpendicular to the  
13 direction of the initial beam 14, thereby creating a  
14 transmit beam 18. The transmit beam 18 enters a series  
15 of transmitter optics 20 which collimates the transmit  
16 beam 18 into a target beam 22. The target beam 22 is  
17 reflected by a target (schematically shown in Fig. 1 as  
18 24) and is returned as a reflected beam 26. The  
19 reflected beam 26 is collected by a series of receiver  
20 optics 28 and directs it to a laser light detector 30.  
21 The axes of the transmit and receiver optics 20, 28 are  
22 calibrated to be coincident at infinity.

23

24 Signals from the detector 30 are sent to a processor  
25 (not shown in Fig. 1), the processor typically forming  
26 part of a computer. The processor calculates the  
27 distance from the unit 10 to the target 24 using a  
28 time-of-flight principle. Thus, by dividing the time  
29 taken for the light to reach the target 24 and be  
30 reflected back to the detector 30 by two, the distance  
31 to the target 24 may be calculated.

32

33 A digital video camera 32 is bore-sighted with the  
34 laser 12 (using the part-silvered prism 16). The  
35 camera 32 is preferably a complementary metal-oxide  
36 silicon (CMOS) camera which is formed on a silicon

1 chip. The chip generally includes all the necessary  
2 drive circuitry for the camera. The camera 32 may be  
3 a zoom CCD (charge coupled device) camera such as a  
4 SONY EVI-371 which is designed for use in camcorders.  
5 The CCD chip is provided with 752 by 582 image cells,  
6 with a cell size in the order of 6.5 microns in the  
7 horizontal direction and 6.25 microns in the vertical  
8 direction. The lens can zoom from 5.4 millimetres (mm)  
9 to 64.2mm focal length in 12 optical settings.

10

11 It should be noted that the camera 32 need not be bore-  
12 sighted with the laser 12. Where the camera 32 is not  
13 bore-sighted with the laser 12, the axis of the laser  
14 12 will be offset from the axis of the camera 32 in the  
15 x and/or y directions. The offset between these axes  
16 can be calculated and the apparatus calibrated (eg  
17 using software) to take account of these offsets.  
18 However, where the camera 32 and the laser 12 are bore-  
19 sighted (as in Fig. 1) there is no requirement to take  
20 account of the offset in any subsequent calculations.  
21 The camera 32 is advantageously capable of zoom  
22 functions as this facilitates selection of targets at  
23 distances up to, or in excess of, 1 km.

24

25 The transmit optics 20 serve a dual purpose and act as  
26 a lens for the camera 32. Thus, light which enters the  
27 transmit optics 20 is collimated and directed to the  
28 camera 32 (shown schematically at 34) thereby producing  
29 an image of the target 24 at the camera 32. The image  
30 which the camera 32 receives is digitised and sent to a  
31 processor (not shown in Fig. 1). It will be  
32 appreciated that a separate lens may be provided for  
33 the camera 32 if required.

34

35 The frame grabber may be of any suitable type, for  
36 example a CREATIVE BLASTER IE500 imaging card (not

1 shown). This card digitises both fields of the  
2 composite video input from the camera 32 and generates  
3 a digital image therefrom.  
4

5 Referring now to Figs 2 and 3, Fig. 2 shows  
6 schematically a first embodiment of apparatus 100  
7 mounted for movement in x and y directions (ie pan and  
8 tilt), and Fig. 3 shows an exploded view of the  
9 apparatus 100 of Fig. 2 in more detail.  
10

11 Referring firstly to Fig. 2, the image capture and  
12 laser transmitter and receiver unit 10 (Fig. 1) is  
13 typically mounted within a casing 50. The casing 50 is  
14 typically mounted to a U-shaped yoke 52, yoke 52 being  
15 coupled to a vertical shaft 54. Shaft 54 is rotatably  
16 mounted to facilitate rotational movement (indicated by  
17 arrow 56 in Fig. 2) of the casing 50 in a horizontal  
18 plane (indicated by axis 58) which is the x-direction  
19 (ie pan). The rotational movement of the shaft 54 (and  
20 thus the yoke 52 and casing 50) is controlled by a  
21 motor 60 coupled to the shaft 54, typically via a  
22 gearbox (not shown in Fig. 2). The operation of the  
23 motor 60 is controlled by the computer.  
24

25 The angle of rotation of the casing 50 in the  
26 horizontal plane (ie panning of the unit 10 in the x-  
27 direction) is measured accurately by a first digital  
28 encoder 62, attached to the shaft 54 in a known manner,  
29 which measures the angular displacement of the casing  
30 50 (and thus the transmit laser beam 22) in the x-  
31 direction.  
32

33 Similarly, the yoke 52 allows the casing 50 (and thus  
34 the transmit laser beam 22) to be displaced in the y-  
35 direction as indicated by arrow 64. The casing 50 is  
36 mounted to the yoke 52 via a horizontal shaft 66.

1 Shaft 66 is rotatably mounted to facilitate rotational  
2 movement (indicated by arrow 64 in Fig. 2) of the  
3 casing 50 in a vertical plane (indicated by axis 68)  
4 which is the y-direction (ie tilt). The rotational  
5 movement of the shaft 66 (and thus the yoke 52 and  
6 casing 50) is controlled by a motor 68 coupled to the  
7 shaft 56, typically via a gearbox (not shown in Fig.  
8 2). The operation of the motor 66 is controlled by the  
9 computer.

10

11 The angle of rotation of the casing 50 in the vertical  
12 plane (ie tilting of the unit 10 in the y-direction) is  
13 measured accurately by a second digital encoder 70,  
14 attached to shaft 66 in a known manner, which measures  
15 the angular displacement of the casing 50 (and thus the  
16 transmit laser beam 22) in the y-direction. Thus, the  
17 motors 60, 68 provide for panning and tilting of the  
18 casing 50.

19

20 The output of the first and second encoders 62, 70 is  
21 electrically coupled to the computer to provide a  
22 feedback loop. The feedback loop is required because  
23 the motors 60, 68 are typically coupled to the shafts  
24 54, 66 via respective gearboxes and are thus not in  
25 direct contact with the shafts 54, 66. This makes the  
26 movement of the casing 50 which is effected by  
27 operation of the motors 60, 68 less accurate. However,  
28 as the encoders 62, 70 are coupled directly to their  
29 respective shafts 54, 66 then the panning and tilting  
30 of the casing in the x- and y-directions can be  
31 measured more accurately, as will be described.

32

33 The embodiment of the image capture and laser  
34 transmitter and receiver unit 10 shown in Fig. 2 is  
35 slightly different from that illustrated in Fig. 1.  
36 The camera 32 within unit 10 is not bore-sighted with

1 the laser 12, and thus casing 50 is provided with a  
2 camera lens 72, a laser transmitter lens 74 and a laser  
3 receiver lens 76. It should be noted that the laser  
4 transmitter lens 74 and the camera lens 72 may be  
5 integrated into a single lens as illustrated in Fig. 1.  
6 Ideally, the camera lens 72, laser transmitter lens 74  
7 and laser receiver lens 76 would be co-axial. This  
8 could be achieved in practice by mechanically adjusting  
9 the lenses 72, 74, 76 to make them co-axial. However,  
10 this is a time consuming process and the offsets  
11 between the lenses can be calculated and the apparatus  
12 can be calibrated to take these offsets into account,  
13 as will be described. This calibration is generally  
14 simpler and quicker than mechanically aligning the  
15 lenses 72, 74, 76.

16

17 Referring to Fig. 3, there is shown in more detail the  
18 apparatus of Fig. 2. It should be noted that the  
19 casing 50 which houses the image capture and laser  
20 transmitter and receiver unit 10 is not provided with a  
21 separate camera lens 72 (as in Fig. 2). It should also  
22 be noted that the casing 50 in Fig. 3 is mounted to  
23 facilitate rotational movement in the x-direction  
24 (pan), but can be manually tilted in the y-direction  
25 (tilt) or can be adapted to the configuration shown in  
26 Fig. 2 for motorised pan and tilt.

27

28 As can be seen more clearly in Fig. 3, the casing 50 is  
29 mounted to the U-shaped yoke 52. The yoke 52 is  
30 coupled to the shaft 54 using any conventional means  
31 such as screws 80. The shaft 54 is driven by the  
32 stepper motor 60 via a worm/wheel drive gearbox 82.  
33 The digital encoder 62 is provided underneath a plate  
34 84 through which the shaft 54 passes and to which the  
35 gearbox/motor assembly is attached. Plate 84 also  
36 includes a rotary gear assembly 86 which is driven by

1 the motor 60 via the worm gearbox 82 to facilitate  
2 rotational movement of the shaft 54.

3  
4 The motor, gearbox and shaft assembly is mounted within  
5 an aluminium casing 86, the casing 86 also having a  
6 rack 88 mounted therein. The rack 88 contains the  
7 necessary electronic circuitry for driving and  
8 controlling the operation of the apparatus, and  
9 includes a stepper motor driver board 90, a laser  
10 control board 92 and an interface board 94.

11  
12 The first and second digital encoders 62, 70 may be of  
13 any conventional type, such as Moir Fringe, barcode or  
14 mask. Moir fringe type encoders are typically used as  
15 they are generally more accurate. Fig. 4 shows a  
16 simplified schematic illustration of a digital encoder,  
17 generally designated 110. Encoder 110 typically  
18 comprises a casing 112 in which a disc 114 is rotatably  
19 mounted. The disc 114 is provided with a pattern and  
20 is typically at least partially translucent. The type  
21 of pattern defined on the disc 114 determines the type  
22 of encoder.

23  
24 A light emitting diode (LED) 116 is suspended above the  
25 disc 114 and emits a light beam (typically collimated  
26 by a lens (not shown) which shines through the disc  
27 114. The light emitted by the LED 116 is detected by a  
28 detector, typically a cell array 118. As the disc 114  
29 rotates (in conjunction with the shaft to which it is  
30 coupled) a number of electrical outputs are generated  
31 per revolution of the disc 114 by the cell array 118  
32 which detects the light passing through the disc 114  
33 from the LED 116. These types of encoders usually have  
34 two output channels (only one shown in Fig. 4) and the  
35 phase relationship between the two signals can be used  
36 to determine the direction of rotation of the disc 114.



1  
2 The encoder 110 produces a pulse output per unit of  
3 revolution. Thus, as the disc 114 rotates, the pattern  
4 on the disc 114 causes electrical pulses to be  
5 generated by the cell array 118 in response to the  
6 pattern on the disc 114. These pulses can be counted  
7 and, given that one pulse is proportional to a certain  
8 degree of rotation, the angular rotation of the disc  
9 114 and thus the shaft 54 can be calculated.

10  
11 In use, the unit 10 is typically externally triggered  
12 by an input device such as a push button, keyboard,  
13 penpad or the like. When the apparatus is triggered,  
14 the camera 32 captures a digitised image of the target  
15 area. The digitised image is made up of a plurality  
16 of pixels, the exact number of which is dependent upon  
17 the size of the image produced by the camera. Each  
18 pixel has an associated x and y co-ordinate which  
19 relate to individual positions in the target area. The  
20 processor is then used to sequentially scan the laser  
21 12 (by moving the part-silvered prism 16 accordingly,  
22 or by using the motors 60, 68 in the Fig. 5 embodiment)  
23 to measure the distance (range) to each successive  
24 point in the target area given by the x and y co-  
25 ordinates of the digitised image. This can then be  
26 used to create three-dimensional co-ordinates (ie x, y  
27 and z) to allow a three-dimensional image of the target  
28 area to be produced, as will be described.

29  
30 Fig. 5 shows the apparatus 100 (schematically  
31 represented in Fig. 5 but shown more clearly in Figs 2  
32 and 3) in use. The apparatus 100 is controlled and  
33 operated using software installed on the computer  
34 (shown schematically at 120) via a cable 122, telemetry  
35 system or other remote or hardwired control. An image  
36 of the target is displayed on the computer screen using

1. the camera 32 (Fig. 1) and is schematically shown as  
2 image 124 in Fig. 5. When the image 124 of the target  
3 area of interest is viewed on the screen, the user of  
4 the apparatus 100 instructs the camera 32 (included as  
5 part of the apparatus 100) to take a freeze frame image  
6 of the target area. The freeze frame image 124 is a  
7 digital image made up of a plurality of pixels and Fig.  
8 6 is a schematic representation of the display produced  
9 on the computer screen of the freeze frame image 124.  
10 The image 124 is typically divided into an array of  
11 pixels, with the image containing, for example, 200 by  
12 200 pixels in the array.

13  
14 Each pixel within the array has an x and y co-ordinate  
15 associated with it using, for example, the centre C of  
16 the picture as a reference point. Thus, each pixel  
17 within the digital image can be individually addressed  
18 using these x and y co-ordinates.

19  
20 The individual addresses for each pixel allow the user  
21 to select a particular object (for example a tree 126)  
22 within the digital image 124. The tree 126 can be  
23 selected using a mouse pointer for example, where the  
24 mouse pointer is moved around the pixels of the digital  
25 image by movement of a conventional mouse provided with  
26 the computer in a known manner. The x and y co-  
27 ordinates of each pixel may be displayed on the screen  
28 as the mouse pointer is moved around the image.  
29 Clicking the mouse button with the pointer on the tree  
30 126 selects a particular pixel 128 within the array  
31 which is identified by its x and y coordinates.

32  
33 The computer is then used to calculate the horizontal  
34 angle  $H_A$  and the vertical angle  $V_A$  (Fig. 6). The  
35 horizontal angle  $H_A$  and the vertical angle  $V_A$  are the  
36 relative angles between the centre point C of the image

1 and the pixel 128, as schematically shown in Fig. 6.

2

3 The methodology for calculating the horizontal angle  $H_A$   
4 and the vertical angle  $V_A$  from the pixel  $x, y$  co-  
5 ordinates is as follows. Fig. 7 is a simplified  
6 schematic diagram of inside the camera 32 which shows  
7 the camera lens 72 and a charge-coupled device (CCD)  
8 array 130. The camera 32 is typically a zoom camera  
9 which therefore has a number of focal lengths which  
10 vary as the lens 72 is moved towards and away from the  
11 CCD array 130.

12

13 Referring to Fig. 7, the angles of horizontal and  
14 vertical views, or the field of view in the horizontal  
15 and vertical direction  $\theta_H, \theta_V$  ( $\theta_V$  not shown in Fig. 7)  
16 can be calibrated and calculated at different focal  
17 lengths of the camera 32. For simplicity, it is  
18 assumed that the CCD array 130 is square, and thus the  
19 field of view in the horizontal and vertical directions  
20  $\theta_H, \theta_V$  will be the same, and thus only the field of view  
21 in the horizontal direction  $\theta_H$  will be considered. The  
22 methodology described below considers one zoom position  
23 only.

24

25 Having calculated (or otherwise obtained eg from the  
26 specification of the camera 32) the field of view in  
27 the horizontal direction  $\theta_H$  then the principal distance  
28 PD (in pixels) can be calculated. The principal  
29 distance PD is defined as the distance from the plane  
30 of the lens 72 to the image plane (ie the plane of the  
31 CCD array 130).

32

33 Referring to Fig. 8, if the image width on the CCD  
34 array is defined as  $H_R$ , then using basic trigonometry  
35  $\tan(\theta_H/2) = H_R/(2PD)$ . Thus,

36

$$PD = H_R / (2 (\tan(\theta_H/2)))$$

1 PD =  $H_R / (2 (\tan(\theta_H/2)))$   
2  
3 If the distance between each pixel in the image 124 in  
4 a certain unit (ie millimetres) is known, then the  
5 principal distance PD can be converted into a distance  
6 in terms of pixels. For example, if the field of view  
7 in the horizontal and vertical angles  $\theta_H$ ,  $\theta_V$  is, for  
8 example  $10^\circ$ , and the image contains 200 by 200 pixels,  
9 then moving one twentieth of a degree in the x or y  
10 direction is the equivalent of moving one pixel in the  
11 x or y direction.

12  
13 When initially using the apparatus 100, the camera 32  
14 is used to take a calibration freeze frame image and  
15 the laser 12 is activated to return the range R to the  
16 centre point C of the image. However, the laser axis  
17 is typically offset from the camera axis. The  
18 horizontal and vertical offsets between the laser axis  
19 and the camera axis when the freeze frame image is  
20 taken are defined as  $H_{offset}$  and  $V_{offset}$  and are known.  
21 Knowing the range R and the horizontal and vertical  
22 offsets  $H_{offset}$ ,  $V_{offset}$  allows the offset horizontal and  
23 vertical distances  $l_x$  and  $l_y$  in terms of pixels to be  
24 calculated. Referring to Fig. 9, the centre point C of  
25 the image 124 taken by the camera 32 and the laser spot  
26 132 where the transmit laser beam 22 hits the target  
27 area is typically offset by the horizontal and vertical  
28 distances  $l_x$  and  $l_y$ .

29  
30 Fig. 10 is a schematic representation illustrating the  
31 horizontal offset  $H_{offset}$  outwith the camera 32, and Fig.  
32 11 is a schematic representation illustrating the  
33 horizontal distance  $l_x$  in terms of pixels, corresponding  
34 to  $H_{offset}$ , within the camera 32. Referring to Figs 10  
35 and 11 and using basic trigonometry,  
36

1  $\tan \theta = H_{\text{offset}}/R$

2 and,

3  $l_x = PD(\tan \theta)$

4 Thus,

5  $l_x = PD(H_{\text{offset}}/R)$

6

7 and it follows that

8  $l_y = PD(V_{\text{offset}}/R)$

9

10 If the range to a certain object within the target area  
11 (such as the tree 126 in Fig. 6) is required, then the  
12 computer must calculate the horizontal and vertical  
13 angles  $H_A$ ,  $H_V$  through which the casing 50 and thus the  
14 laser beam 22 must be moved in order to target the  
15 object.

16

17 The user selects the particular pixel (relating to the  
18 object of interest) within the image using a mouse  
19 pointer. In Fig. 12, the selected object is  
20 represented by pixel A which has coordinates  $(x, y)$ ,  
21 and the laser spot 132 has coordinates  $(l_x, l_y)$   
22 calculated (eg by the computer 120) using the previous  
23 method. The coordinates  $(x, y)$  of point A are already  
24 known (by the computer 120) using the coordinates of  
25 the pixel array of the image.

26

27 If the horizontal distance between pixel A and the  
28 laser spot 132 is defined as  $d_x$ , and similarly the  
29 vertical distance between pixel A and the laser spot  
30 132 is defined as  $d_y$ , then

31

32  $d_x = x - l_x$

33 and

34  $d_y = y - l_y$

35

36 and it follows that the horizontal and vertical angles

1  $H_A$ ,  $V_A$  can be calculated as

2

3  $H_A = \text{inverse tan } (d_x/PD)$

4

5 and

6  $V_A = \text{inverse tan } (d_y/PD)$ .

7

8 Referring back to Fig. 2, having calculated the  
9 horizontal and vertical angles  $H_A$ ,  $V_A$  through which the  
10 casing 50 must be rotated to measure the range to the  
11 object A, the computer 120 instructs the motor 60 to  
12 pan through an angle of  $H_A$  and simultaneously instructs  
13 the motor 68 to tilt through an angle of  $V_A$ . Thus, the  
14 transmit laser beam 22 is directed at the object A  
15 selected by the user to determine the range to it.  
16

17 However, the motors 60, 68 are not directly coupled to  
18 the shafts 54, 66 (but via respective gearboxes) and  
19 thus can have errors which results in the laser beam 22  
20 not being directed precisely at the object A. However,  
21 the encoders 62, 70 can be used to measure more  
22 precisely the angles  $H_A$  and  $V_A$  through which the casing  
23 50 was panned and tilted. If there is a difference  
24 between the measured angles  $H_A$  and  $V_A$  and the angles  
25 which were calculated as above, the computer can  
26 correct for this and can pan the casing 50 through an  
27 angle  $H_{AC}$  which is the difference between the calculated  
28 angle  $H_A$  and the measured angle  $H_A$ , and similarly tilt  
29 the casing 50 through an angle  $V_{AC}$  which is the  
30 difference between the calculated angle  $V_A$  and the  
31 measured angle  $V_A$ . The process can then be repeated by  
32 using the encoders 62, 70 to check that the casing 50  
33 has been panned and tilted through the angles  $H_{AC}$  and  
34  $V_{AC}$ . If there is a difference again, then the process  
35 can be repeated to further correct for the errors  
36 introduced. This iteration process can be continued

1 until the output from the encoders 62, 70 corresponds  
2 to the correct angles  $H_A$  and  $V_A$ . The laser 12 is then  
3 fired to give the range to the object A.  
4

5 The calibration process described above is typically an  
6 automated process for the calibration of the interior  
7 and exterior parameters of the camera. The calibration  
8 process typically determines the accuracy of the  
9 measurements and the realism of the three dimensional  
10 image produced. The main function of the calibration  
11 process is to calibrate a principal point PP and the  
12 principal distance PD using image-processing  
13 techniques.  
14

15 The principal point PP is based on the assumption that  
16 the optical axis of the camera 32 is straight so that  
17 the principal point PP for all zoom lenses falls at one  
18 point on the image. When the camera 32 zooms in, the  
19 targets on the image move towards the centre of the  
20 image. The intersection of all target paths, whilst  
21 zooming, is considered as the principal point PP. The  
22 control program used for the automatic calibration  
23 process enables the user to select targets whilst  
24 zooming in and out. The processor then calculates the  
25 average of the intersections of all target paths, which  
26 is considered as the principal point PP. The principal  
27 point PP is typically calculated several times and the  
28 average of these calculations is taken to be the  
29 principal point PP.  
30

31 The principal distance PD varies with zoom lenses. At  
32 each zoom position, the calibration begins with  
33 pointing the apparatus 100 so that the central part of  
34 the image is filled with the target area. The central  
35 part of the image is typically a rectangle. The  
36 angular readings of the apparatus (eg from the encoders

1 62, 70) are recorded. A pixel with the most unique  
2 surrounding features within the central part is  
3 selected as a target point and its image and  
4 coordinates are recorded as described above. This  
5 target point typically has the most features and should  
6 be relatively easy to match.

7  
8 The apparatus 100 is then panned and/or tilted to five  
9 positions along the four main directions; that is up,  
10 down, left and right. At each position, a  
11 corresponding image is grabbed using the imaging card  
12 (frame grabber) and the camera 32 and the angular  
13 settings (eg from the encoders 62, 70) of the apparatus  
14 100 are recorded. The central part of the image is  
15 then moved to enclose the moved target point by best  
16 estimate from the previous calibration data. The  
17 target point is then searched and located with sub-  
18 pixel precision by area-based matching techniques. A  
19 check may be performed using, for example, back  
20 matching to discard unreliable matchings. If both  
21 horizontal and vertical directions have four matches  
22 discarded in this manner, recalibration is suggested.  
23 At least seven sets of locations of the target  
24 (including the initial target location) with respect to  
25 the angular settings of the apparatus 100 can be  
26 obtained along the horizontal and vertical directions.  
27 If the calibration results in the horizontal and  
28 vertical directions are valid, the average value is  
29 taken. A further check on the reliability of the  
30 matching can be conducted on the basis of least squares  
31 solution.

32  
33 This calibration method can be conducted automatically  
34 without the need for setting special targets which  
35 enables the user to carry out the procedure at any  
36 time. It also facilitates regular instrument check-up.



1 The automation without the use of set targets greatly  
2 reduces the cost of the calibration and considerably  
3 increases the ease of use of the calibration utility.  
4

5 Referring again to Fig. 6, to obtain a three  
6 dimensional (3D) image of the tree 126, the user can  
7 select a number of pixels around the outline of the  
8 tree 126. This selection limits the number of points  
9 which are used to create a 3D image. It should be  
10 noted however, that a 3D representation of the whole  
11 image 124 can be created.  
12

13 Having selected the outline of the target (ie tree  
14 126), the software provided on the computer 120  
15 instructs the motors 60, 68 to pan and tilt the unit 10  
16 through respective horizontal and vertical angles  $H_A$ ,  $V_A$   
17 corresponding to the pixels within the tree 126 (or the  
18 entire image 124 as required). The same iterative  
19 process as described above can be used to ensure that  
20 the laser 12 is accurately directed to each of the  
21 pixels sequentially. At each pixel, the laser 12 is  
22 activated to obtain the range R to each of the pixels  
23 within the tree 126, as previously described.  
24

25 Once the horizontal and vertical angles  $H_A$ ,  $V_A$  and the  
26 range R of each of the pixels is known, the processor  
27 within the computer 120 can then be used to calculate  
28 the 3D co-ordinates of the pixels within the tree 126  
29 to recreate a 3D image of the tree 126.  
30

31 Referring to Fig. 14, the central laser spot 132 has an  
32 offset  $l_x$  and  $l_y$  as described above, and also has  
33 horizontal and vertical angles  $H_0$ ,  $V_0$  and range  $R_0$ .  
34 Determination of the pixel x and y coordinates  $p_x$ ,  $p_y$   
35 for the point A which has horizontal and vertical  
36 angles H, V and range R, can be done as follows using

1 basic trigonometry. It should be noted that the field  
2 of view in the horizontal and vertical directions  $\theta_H$ ,  
3  $\theta_V$ , the principal distance PD and the horizontal and  
4 vertical distances  $l_x$  and  $l_y$  are either all known or can  
5 be calculated as described above.

6

$$7 \quad p_x - l_x = PD \tan(H - H_0)$$

8 and

$$9 \quad p_y - l_y = PD \tan(V - V_0).$$

10

11 It thus follows that

12

$$13 \quad p_x = l_x + PD \tan(H - H_0)$$

14 and

$$15 \quad p_y = l_y + PD \tan(V - V_0).$$

16

17 Thereafter, the 3D coordinates  $x$ ,  $y$ ,  $z$  for the point A  
18 can be calculated, as will be described with reference  
19 to Fig. 15.

20

21 Using trigonometry,

22

$$23 \quad x = R \cos V \cos H$$

$$24 \quad y = -R \cos V \sin H$$

25 and

$$26 \quad z = R \sin V$$

27

28 These calculations can then be repeated for each pixel  
29 (defined by  $p_x$ ,  $p_y$ ) to give 3D coordinates for each of  
30 the pixels within the target (ie tree 126 or image  
31 124). An array of pixel co-ordinates  $p_x$ ,  $p_y$  and the  
32 corresponding 3D coordinates  $x$ ,  $y$ ,  $z$  can be created and  
33 the processor within the computer 120 can be used to  
34 plot the 3D coordinates using appropriate software.  
35 Appendix A shows an exemplary array of pixel co-  
36 ordinates  $p_x$ ,  $p_y$  and the corresponding 3D coordinates  $x$ ,

1 y, z of a bitmap image which can be used to generate a  
2 3D image.

3 )

4 Once the 3D coordinates have been plotted, the software  
5 then generates a profile of the 3D image using  
6 triangles to connect each of the 3D coordinates  
7 together, as shown in Fig. 16. Fig. 16 is a print of  
8 the triangular framework used to recreate a 3D image of  
9 a bitmap photograph. The bitmap image (ie the digital  
10 image taken by the camera 32) is then superimposed on  
11 the triangulated image to construct a 3D image of the  
12 target (ie tree 126 or image 124). Fig. 17 shows a  
13 print of a 3D image which used a bitmap photograph  
14 superimposed on the framework of Fig. 16. The 3D image  
15 of the target can typically be viewed from all angles  
16 using the software. Thus, the user can effectively  
17 walk around the tree 126. However, this may require a  
18 number of photographs (ie digital bitmap images taken  
19 by the camera 32) at different angles which can then be  
20 superimposed upon one another to create a full 360° 3D  
21 image. It should be noted that even when using only  
22 one photograph, the user can manipulate the 3D image to  
23 look at the tree 126 from all angles.

24

25 It should also be noted that having a bitmap (colour)  
26 image of the tree 126 (and image 124) allows accurate  
27 (true) colours to be assigned to each pixel within the  
28 image. Conventionally, colours are assigned from a  
29 palette which may not be the true and original colours.

30

31 The software may also be capable of allowing the user  
32 to select two points within the tree 126 and  
33 calculating the horizontal and vertical distances  
34 between the two points. Thus, it is possible for the  
35 user to determine, for example, the height of the tree  
36 by using the mouse to select a pixel at the top and

1 bottom of the tree 126. If a building is plotted in 3D  
2 using the above methodology, the software can be used  
3 to determine the height, width and depth of the  
4 building, and also other parameters such as the length  
5 of a window, the height of a door and the like. To  
6 enable the used to select points more accurately, the  
7 software is advantageously provided with zoom  
8 capabilities.

9  
10 The software may also be capable of plotting the  
11 profile of the tree using gradiented colours to show  
12 the horizontal distance, vertical distance and/or range  
13 to each of the pixels within the tree 126 or image 124.

14  
15 Additionally, the software may be capable of allowing  
16 the user to select one or more points whereby a profile  
17 of the tree 126 in the plane selected can be shown.

18 Additionally, the profiles in the x, y and z directions  
19 through one particular point within the image can also  
20 be plotted. It is also possible for the x, y and z  
21 axes to be superimposed on the image, and directional  
22 axes (ie north, south, east and west) can also be  
23 superimposed upon the image.

24  
25 Instead of superimposing the bitmap (digital) image  
26 over the triangular wireframe, the software may be used  
27 to create a shaded image of the target and may also be  
28 capable of changing the position of the light which  
29 illuminates the target.

30  
31 It will also be appreciated that the software can  
32 generate x, y and/or z contours which may be  
33 superimposed over the image.

34  
35 Referring back to Fig. 5, the apparatus 100 can  
36 optionally include a Global Positioning System (GPS)

1 (not shown). GPS is a satellite navigation system  
2 which provides a three-dimensional position of the GPS  
3 receiver (in this case mounted as part of the apparatus  
4 100) and thus the position of the apparatus 100. The  
5 GPS is used to calculate the position of the apparatus  
6 100 anywhere in the world to within approximately  $\pm 25$   
7 metres. The GPS calculates the position of the  
8 apparatus 100 locally using radio/satellite broadcasts  
9 which send differential correction signals to  $\pm 1$   
10 metre. The GPS can also be used to record the time of  
11 all measured data to 1 microsecond.  
12

13 The apparatus 100 advantageously includes an  
14 inclinometer (not shown) and a fluxgate compass (not  
15 shown), both of which would be mounted within the  
16 casing 50 (Fig. 2). The fluxgate compass generates a  
17 signal which gives a bearing to the target and the  
18 inclinometer generates a signal which gives the incline  
19 angle to the target. These signals are preferably  
20 digitised so that they are in a machine-readable form  
21 for direct manipulation by the computer 120.  
22

23 Thus, in addition to being used to find ranges to  
24 specific targets, the apparatus may also be used to  
25 determine the position of objects, such as electricity  
26 pylons, buildings, trees or other man-made or natural  
27 structures. The GPS system can be used to determine  
28 the position of the apparatus 100 anywhere in the  
29 world, which can be recorded. Optionally, the fluxgate  
30 compass within the casing 50 measures the bearing to  
31 the target, which can be used to determine the position  
32 of the target using the reading from the GPS system and  
33 the reading from the fluxgate compass.  
34

35 The positional information, the bearing and the  
36 inclination to the target can optionally be

1     superimposed on the 3D image.

2

3     It should also be noted that the encoders 62, 70 may be  
4     used to determine the bearing to the target instead of  
5     the fluxgate compass. In this case, if the encoder is  
6     given an absolute reference, such as the bearing to an  
7     electricity tower or other prominent landmark which is  
8     either known or can be calculated, then the angle  
9     relative to the reference bearing can be calculated  
10    using the outputs from the encoders 62, 70, thus giving  
11    the bearing to the target.

12

13    In addition, the position of the apparatus and the  
14    calculated position of the target could be overlayed on  
15    a map displayed on the computer screen so that the  
16    accuracy of the map can be checked. This would also  
17    allow more accurate maps to be drawn.

18

19    Fig. 18 shows an alternative embodiment of a mounting  
20    device for the apparatus generally designated 150. The  
21    apparatus 150 includes a hard-hat type helmet 152. The  
22    helmet 152 may be replaced by any suitable form of  
23    headgear, but is used to give a user 154 some form of  
24    protection during use. This is advantageous where the  
25    user 154 is working in hazardous conditions, such as on  
26    a building site, quarry or the like. The helmet 152 is  
27    typically held in place on the head of the user 154  
28    using a chin strap 156.

29

30    Mounted within the helmet 152, and preferably  
31    integrally moulded therein, is a Global Positioning  
32    System (GPS) 158. The GPS 158 is a system which  
33    provides a three-dimensional position of the GPS  
34    receiver (in this case mounted within the helmet 152 on  
35    the user 154) and thus the position of the user 154.  
36    The GPS 158 is used to calculate the position of the

1 user 154 anywhere in the world to within approximately  
2  $\pm 25$  metres. The DGPS calculates the position of the  
3 user 154 locally using radio/satellite broadcasts which  
4 send differential correction signals to  $\pm 1$  metre. The  
5 GPS 158 can also be used to record the time of all  
6 measured data to 1 microsecond.

7  
8 The GPS 158 is coupled to a computer (similar to  
9 computer 120 in Fig. 5) via a serial port. The  
10 computer may be located in a backpack 160, shown  
11 schematically in Fig. 18, or may be a portable  
12 computer, such as a laptop. The backpack 160 has a  
13 power source, such as a battery pack 162, either formed  
14 integrally therewith, or as an external unit.

15  
16 Mounted on the helmet 152 is a housing 164 which  
17 encloses the range finder (as shown in Fig. 1), the  
18 video camera 32, an inclinometer (not shown) and a  
19 fluxgate compass (not shown). Signals from the range  
20 finder, camera 32, compass and inclinometer are fed to  
21 the computer in the backpack 160 via a wire harness  
22 166.

23  
24 The fluxgate compass generates a signal which gives a  
25 bearing to the target and the inclinometer generates a  
26 signal which gives the incline angle to the target.  
27 These signals are preferably digitised so that they are  
28 in a machine-readable form for direct manipulation by  
29 the computer.

30  
31 The video camera 32 is preferably a charge-coupled  
32 device (CCD) camera. This type of camera operates  
33 digitally and allows it to be directly interfaced to  
34 the computer in the backpack 160. Signals from the  
35 camera 32 are typically input to the computer via a  
36 video card. The camera 32 may be, for example, a six-

1 times magnification, monochrome camera with laser  
2 transmitter optics.

3  
4 The view from the camera 32 is displayed on an eyepiece  
5 VGA monitor 168 suspended from the helmet 152. The  
6 monitor 168 is coupled to the computer in the backpack  
7 160 via a second wire harness 170. The monitor 168 is  
8 used to display computer graphics and a generated  
9 graphics overlay.

10  
11 The mounting of the monitor 168 on the helmet 152 is  
12 independent of the housing 164 and is thus adjustable  
13 to suit a plurality of individual users. A tri-axial  
14 alignment bracket (not shown) is provided for this  
15 purpose.

16  
17 In use, software which is pre-loaded on the computer in  
18 the backpack 160 enables the user 154 to see a video  
19 image (provided by the camera 32) of the target on the  
20 monitor 168. The software can overlay the video image  
21 with a sighting graticule (not shown) and any measured  
22 data in a separate window.

23  
24 It should be noted from Fig. 1 that the camera 32 and  
25 the laser range finder are bore-sighted. Conventional  
26 systems use an offset eyepiece sighting arrangement  
27 with an axis which is aligned and collimated to be  
28 parallel to the axis of the laser range finder.  
29 However, use of the camera 32 (which displays an image  
30 of the target area on the VGA monitor eyepiece 168)  
31 bore-sighted with the laser range finder provides the  
32 user 154 with an exact view of the target area using  
33 the camera 32. Thus, there is no need for a collimated  
34 eyepiece and the user 154 can be sure that the range  
35 finder will be accurately directed at the target. To  
36 further improve accuracy, computer controlled graticule



1 offsets may be generated during a calibration and  
2 collimation procedure to eliminate residual errors of  
3 alignment between the laser range finder and the camera  
4 32. These offset values may be stored in an erasable-  
5 programmable-read-only-memory (EPROM) for repetitive  
6 use.

7  
8 Operation of the apparatus 150 is controlled by an  
9 input device 172 connected to the computer via a  
10 keyboard input. The input device 172 typically  
11 comprises a keyboard, keypad, penpad or the like, and  
12 controls different functions of the apparatus 150.

13  
14 When an observation or survey is required of a  
15 particular target area, the user 154 views the target  
16 area using the camera 32 and the eyepiece monitor 168.  
17 The target area is aligned with the graticule typically  
18 using a small circle (not shown) or a cross as a guide.

19  
20 The user 154 then fires the apparatus 150 using an  
21 appropriate key or button on the input device 172. The  
22 computer initiates the camera 32 which captures a  
23 digital image of the target area and scans the laser 12  
24 to provide a 3D image of the target area as previously  
25 described. It should be noted that the panning and  
26 tilting of the laser 12 is not achieved by motors 60,  
27 68 as in the Fig. 2 embodiment. In this example, the  
28 part-silvered prism 16 can be moved to scan the laser  
29 over the target to provide range information for each  
30 pixel within the target.

31  
32 In addition, measurements of the various parameters  
33 such as bearing and incline to the target area are  
34 recorded, digitised and incorporated into the  
35 calculations made by the computer. The global position  
36 of the user 154 and the time of the measurement is also

1 recorded from the GPS/DGPS 158.

2

3 The calculated and/or measured data is then sent from  
4 the computer to the monitor 168 and is displayed in a  
5 window of the image by refreshing the data therein.

6 This allows the user 154 to see the measured data and  
7 confirm that the correct target area has been  
8 identified and accurately shot by reference to the  
9 freeze frame image and the overlaid data window and  
10 reticule.

11

12 The user 154 may then save either the data, image or  
13 both to the memory in the computer using an appropriate  
14 push button (not shown) on the input device 172.

15 Multiple measurements of this nature may be recorded,  
16 for each pixel, thus giving 3D images of different  
17 target areas. These images may then be used to observe  
18 the target area either in real-time or later to assess  
19 and/or analyse any of the geographical features.

20

21 For example, one particular use would be by the  
22 military. During operations, a squad may be required  
23 to cross a river. The apparatus may be used to create  
24 multiple 3D images of possible crossing places, for  
25 example by deploying the apparatus on an elevated  
26 platform. These would then be assessed to select the  
27 best location for a mobile bridge to be deployed. The  
28 image may be viewed locally or could be transmitted in  
29 a digital format to a command post or headquarters  
30 anywhere in the world. Use of the apparatus would  
31 result in much faster and more accurate observations of  
32 the geographical locations and would avoid having to  
33 send soldiers into the area to visually assess the  
34 locations and report back. The apparatus may be  
35 deployed on an elevated platform and operated by remote  
36 control to decrease the risk to human users in hostile

1 situations.

2

3 Referring to Figs 19a to 19c, there is shown a vehicle  
4 180 (such as a tank) which is provided with the  
5 apparatus 100 of Figs 2 and 3 mounted on a telescopic  
6 or extendable arm 182. As illustrated in Fig. 19a, the  
7 apparatus 100 may be completely retracted when the  
8 vehicle 180 is in motion, and may be stored behind an  
9 armoured shield 184. The casing 50 of the apparatus  
10 100 would tilt downwards to a horizontal attitude and  
11 the telescopic arm 182 would extend so that the  
12 apparatus 100 was substantially protected by the  
13 armoured shield 184.

14

15 When the area to be surveyed is reached, the vehicle is  
16 stopped and the apparatus 100 deployed on the  
17 telescopic arm 182 by reversing the procedure described  
18 above, as illustrated in Fig. 19b. The telescopic arm  
19 182 is preferably mounted on a rotation joint 186 so  
20 that the apparatus 100 can be rotated through 360° as  
21 indicated by arrow 188 in the enlarged portion of Fig.  
22 19b. A motor 190 is coupled to the rotation joint 186  
23 to facilitate rotation of the joint 186. The apparatus  
24 100 can typically be raised to a height of  
25 approximately 15 metres or more, depending upon the  
26 construction of the arm 182.

27

28 The particular configuration shown in Figs 19a and 19b  
29 can accommodate large angles of roll and pitch of the  
30 vehicle, such as that shown in Fig. 19c. In Fig. 19c,  
31 the vehicle 180 is stationary on a slope 192 and has  
32 been rolled through an angle indicated by arrow 185 in  
33 Fig. 19c. The user or the computer can correct for the  
34 angle of roll 185 by moving the arm 182 until the  
35 inclinometer indicates that the apparatus 100 is level.  
36 A level 198 (Figs 20a, 20b) may be provided on the base

1 of the apparatus 100 if required.

2

3 Figs 20a and 20b are front and side elevations of the  
4 apparatus 100 mounted on the arm 182. As can be seen  
5 from Figs 20a and 20b, the arm 182 can be rotated  
6 through 360° as indicated by arrow 196 in Fig. 20a.  
7 The apparatus 100 is mounted on a pan and tilt head 200  
8 to facilitate panning and tilting of the apparatus 100.

9

10 Servo motors within the pan and tilt head 200 pan and  
11 tilt the head 200 into the plane of roll and pitch of  
12 the vehicle 180 (Fig. 19c). Thereafter, the motors 60,  
13 68 of the apparatus 100 pan and tilt the apparatus 100  
14 until it is level, using the level indicator 198 as a  
15 guide.

16

17 Further electronic levels (not shown) within the  
18 apparatus 100 can measure any residual dislevelment and  
19 this can be corrected for in the software before any  
20 measurements are taken.

21

22 A particular application of the apparatus 100 deployed  
23 on a vehicle 180 would be in a military operation. The  
24 apparatus 100 can be deployed remotely on the arm 182  
25 and used to survey the area surrounding the vehicle 180  
26 to create a 3D real-time image of the terrain.

27

28 Alternatively, or additionally, the computer 120 could  
29 be provided with a ground modelling software package  
30 wherein the user selects a number of key targets within  
31 the area using the method described above, and finds  
32 the range and bearing to, height of and global position  
33 of (if required) these targets. The software package  
34 will then plot these points, including any heights  
35 which a GPS 202 (Figs 20a and 20b) can generate, and  
36 in-fill or morph the remaining background using digital

1 images captured by the camera 32 to produce a 3D image  
2 of the terrain, as described above.

3 ,  
4 The surveying operation can be done discretely and in a  
5 very short time compared with conventional survey  
6 techniques and provides a real-time 3D image of the  
7 terrain. Once the terrain has been modelled, design  
8 templates of equipment carried by the vehicle 180 (or  
9 any other vehicle, aircraft etc) can be overlaid over  
10 the image to assess which type of equipment is required  
11 to cross the obstacle, such as a river.

12  
13 Conventional techniques would typically require to  
14 deploy a number of soldiers to survey the area manually  
15 and report back. However, with the apparatus 100  
16 deployed on the vehicle 180 the survey can be done  
17 quicker, more accurately and more safely, without  
18 substantial risk to human life.

19  
20 It is possible to conduct multiple surveys with the  
21 vehicle 180 in one or more locations, with the data  
22 from each survey being integrated to give a more  
23 accurate overall survey of the surrounding area.

24  
25 Furthermore, if the arm 182 was disposed at the front  
26 of the vehicle 160 as shown in Figs 21a and 21b, the  
27 apparatus 100 can be used to check the profile of the  
28 ground in front of the vehicle 180. Thus, the profile  
29 of the ground could be shown in 3D which would allow  
30 the driver of the vehicle (or other personnel) to  
31 assess the terrain and warn of any dangers or  
32 difficulties.

33  
34 Alternatively, or additionally, the software on the  
35 computer 120 could be used to generate a head-up video  
36 display to which the driver of the vehicle 180 could

1 refer. The heading of the tank (measured by the  
2 fluxgate compass) could also be displayed, with the  
3 range to and height of the ground (and any  
4 obstructions) in front of the vehicle 180 also being  
5 displayed. The height displayed could be the height  
6 relative to the vehicles' position, or could be the  
7 absolute height obtained from the GPS 202.

8  
9 Another application of the apparatus 110 would be to  
10 capture images of electricity pylons for example by  
11 targeting each individually and saving the data for  
12 future reference (for example to allow their positions  
13 on a map to be plotted or checked) or to observe them  
14 in 3D to check for any faults or the like.

15  
16 In addition to providing the 3D image of the target  
17 area, the computer may also calculate the position of  
18 the target area using the GPS/DGPS 158 (Fig. 18). The  
19 position of the user 154 is recorded using the GPS/DGPS  
20 158, and by using the measurements such as bearing and  
21 inclination to the target area, the position of the  
22 target area may thus be calculated.

23  
24 The apparatus provides a 3D image of the target area  
25 which, in a geographical format, may be used to update  
26 map information and/or object dimensions and positions.  
27 The software may overlay and annotate the measured  
28 information on background maps which may be stored, for  
29 example, on compact-disc-read-only-memory (CD-ROM) or  
30 any other data base, such as Ordnance Survey maps.

31  
32 Using a separate function on the input device 172, the  
33 user can change the image on the monitor 168 to show  
34 either a plot of the user's position (measured by the  
35 GPS/DGPS 158) superimposed on the retrieved data base  
36 map, or to view updated maps and/or object dimensions

1 and positions derived from the measurements taken by  
2 the apparatus 100.

3 )

4 Fig. 22 shows a concept design of an alternative  
5 apparatus 210. The apparatus 210 is mounted on a head  
6 band 212 which rests on the head of a user 214.

7 Mounted on the headband 212 is a housing 224 which is  
8 attached to the headband 212. The housing 224 encloses  
9 the apparatus 100 (Fig. 5) as previously described.  
10 This particular embodiment incorporates an eyepiece  
11 monitor 250 into the housing 224.

12

13 Figs 23 to 30 show a hand-held housing for the  
14 apparatus. The hand-held device 300 includes an  
15 eyepiece 310 which is used to select the target area.  
16 Device 300 includes an image capture and laser  
17 transmitter and receiver unit 10 similar to that shown  
18 schematically in Fig. 1.

19

20 In use, a user 314 (Figs 28 to 30) puts the eyepiece  
21 310 to his eye and visualises the target through a lens  
22 312. When the target has been visualised, a fire  
23 button 315 is depressed which initiates the camera 32  
24 (Fig. 1) to take a digital (two-dimensional) image of  
25 the target, which can be displayed on a small LCD  
26 screen 316. The laser range finder can then be used to  
27 determine the range to each pixel using the methodology  
28 described herein to allow a 3D image to be produced.  
29 It should be noted that the hand-held device 300 need  
30 not be capable of processing the 3D image. The range  
31 to each pixel can be recorded and stored in a file for  
32 transfer to a computer (provided with the appropriate  
33 software) which may be used to reproduce the 3D image.  
34 The device 300 is typically provided with a suitable  
35 interface for downloading, or may be provided with an  
36 alternative storage means such as an EPROM which may be

1 removed from the device as required, or a floppy disc  
2 drive for example.

3  
4 It will be apparent that the apparatus and method  
5 described herein can be used to produce three  
6 dimensional images of a plurality of different targets  
7 and may be used in a wide range of applications. These  
8 applications include quarry sites, onshore and offshore  
9 oil and gas installations, building sites including  
10 individual buildings or the like.

11  
12 It will also be apparent that the apparatus and method  
13 described herein may be used for applications other  
14 than surveying, such as obtaining three dimensional  
15 images for computer games or the like.

16  
17 Modifications and improvements may be made to the  
18 foregoing without departing from the scope of the  
19 invention.

20



1

2

**CLAIMS**

3

4

1. An apparatus comprising an imaging device, a range finder, and a processor capable of receiving and processing image and range signals to construct a three-dimensional image from said signals.

8

9

2. The apparatus according to claim 1, wherein the imaging device comprises a camera.

11

12

3. The apparatus according to either preceding claim, wherein the imaging device comprises a digital video camera.

14

15

16

4. The apparatus according to any preceding claim 2, wherein the imaging device is capable of zoom functions.

18

19

20

5. The apparatus according to any preceding claim, wherein the apparatus includes a display device to allow a user to view a target area using the imaging device.

23

24

25

6. The apparatus according to any preceding claim, wherein the apparatus includes a pan and tilt unit for panning and tilting of the range finder and/or imaging device.

28

29

30

7. The apparatus according to claim 6, wherein the pan and tilt unit comprises a first motor for panning of the range finder and/or imaging device, and a second motor for tilting of the range finder and/or imaging device.

34

35

36

8. The apparatus according to claim 7, wherein the

1 first and second motors are controlled by the  
2 processor.

3 )

4 9. The apparatus according to any one of claims 6 to  
5 8, wherein the pan and tilt unit includes first and  
6 second digital encoders for measuring the angles of pan  
7 and tilt respectively.

8

9 10. The apparatus according to claim 9, wherein the  
10 outputs of the first and second encoders are fed to the  
11 processor.

12

13 11. The apparatus according to any preceding claim,  
14 wherein the image is digitised.

15

16 12. The apparatus according to any preceding claim,  
17 wherein the image comprises a plurality of pixels.

18

19 13. The apparatus according to any preceding claim,  
20 wherein the image comprises a captured image.

21

22 14. The apparatus according to any preceding claim,  
23 wherein the range finder comprises a laser range  
24 finder.

25

26 15. The apparatus according to any preceding claim,  
27 wherein the range finder is bore-sighted with the  
28 imaging device.

29

30 16. The apparatus according to any preceding claim,  
31 wherein the apparatus includes a compass and an  
32 inclinometer and/or gyroscope.

33

34 17. The apparatus according to any preceding claim,  
35 wherein the apparatus further includes a position  
36 fixing system for identifying the geographical position

1 of the apparatus.

2

3 18. The apparatus according to claim 17, wherein the  
4 position fixing system is a Global Positioning System  
5 (GPS).

6

7 19. The apparatus according to any preceding claim,  
8 wherein the apparatus is operated by remote control.

9

10 20. The apparatus according to any preceding claim,  
11 wherein the apparatus is controlled by an input device.

12

13 21. The apparatus according to claim 20, wherein the  
14 input device facilitates operation of a particular  
15 function of the apparatus.

16

17 22. A method of generating a three-dimensional image  
18 of a target area, the method comprising the steps of  
19 providing an imaging device, providing a range finder,  
20 operating the imaging device to provide an image of the  
21 target area, and subsequently measuring the distance to  
22 each of a plurality of points by scanning the range  
23 finder at preset intervals relating to the points.

24

25 23. A method according to claim 22, wherein the method  
26 includes the further steps of

27

28

29

30

31

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33

34

35

36

24. A method according to claim 22 or claim 23,  
wherein the method includes the further steps of  
digitising the image to provide a plurality of  
pixels within the digital image;  
calculating horizontal and vertical angles between  
a reference point in the image and each pixel;

1 moving the range finder through the horizontal and  
2 vertical angles whereby the range finder is  
3 directed at each pixel in sequence; and  
4 actuating the range finder to obtain a range to  
5 the target corresponding to the position of the  
6 pixel.

7  
8 25. A method according to claim 24, wherein the method  
9 includes the additional steps of  
10 assigning x and y coordinates for each pixel  
11 within the image;  
12 correlating the range to the target with each  
13 pixel within the image; and  
14 calculating three dimensional coordinates of the  
15 pixels to reconstruct a three dimensional image of  
16 the target area.

17  
18 26. A method according to claim 25, wherein the method  
19 includes the additional steps of  
20 plotting each of the three dimensional points of  
21 the image; and  
22 superimposing a wire frame over the image  
23 connecting each of the three dimensional points.

24  
25 27. A method according to claim 26, wherein the method  
26 includes the additional step of superimposing the image  
27 on the wire frame to reconstruct a three dimensional  
28 image of the target area.

29  
30 28. A method according to any one of claims 24 to 27,  
31 the method including the further steps of  
32 obtaining a horizontal offset and a vertical  
33 offset between an axis of the camera and an axis of the  
34 range finder;  
35 calculating the horizontal and vertical offsets in  
36 terms of pixels;

1       calculating the difference between the horizontal  
2       and vertical offsets in terms of pixels and the x and y  
3       coordinates of the target pixel; and  
4       calculating the horizontal and vertical angles.  
5

6       29. A method according to any one of claims 24 to 28,  
7       wherein the method includes the further steps of  
8       providing the range finder and/or camera on a pan  
9       and tilt unit;  
10       providing angle encoders to measure the angles of  
11       pan and tilt of the unit;  
12       instructing the pan and tilt unit to pan and tilt  
13       the range finder and/or camera through the vertical and  
14       horizontal angles;  
15       measuring the horizontal and vertical angles using  
16       the encoders;  
17       verifying that the angles through which the range  
18       finder and/or camera are moved is correct;  
19       obtaining horizontal and/or vertical correction  
20       angles by subtracting the measured horizontal and  
21       vertical angles from the calculated horizontal and  
22       vertical angles;  
23       adjusting the pan and tilt of the range finder  
24       and/or camera if necessary; and  
25       activating the range finder to obtain the range to  
26       the target.  
27  
28

1 / 17

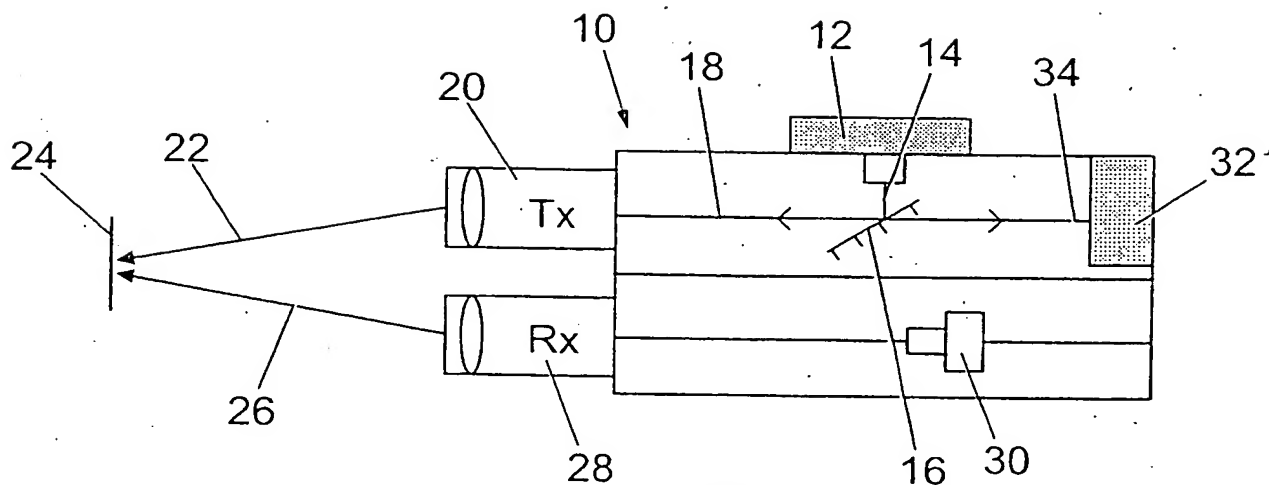


Fig. 1

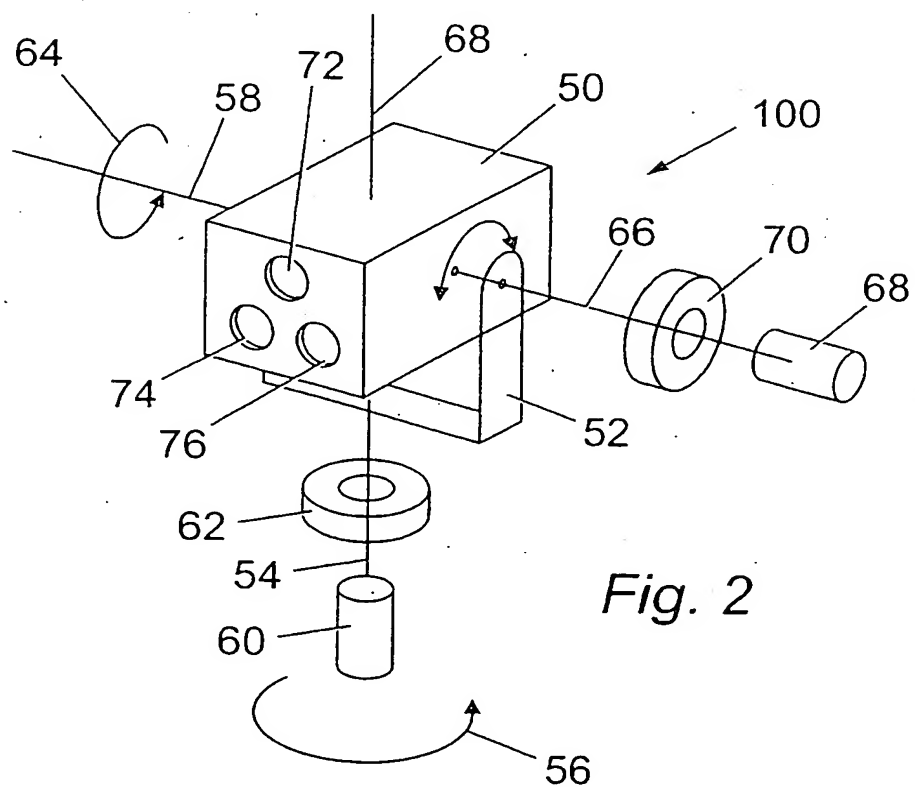


Fig. 2

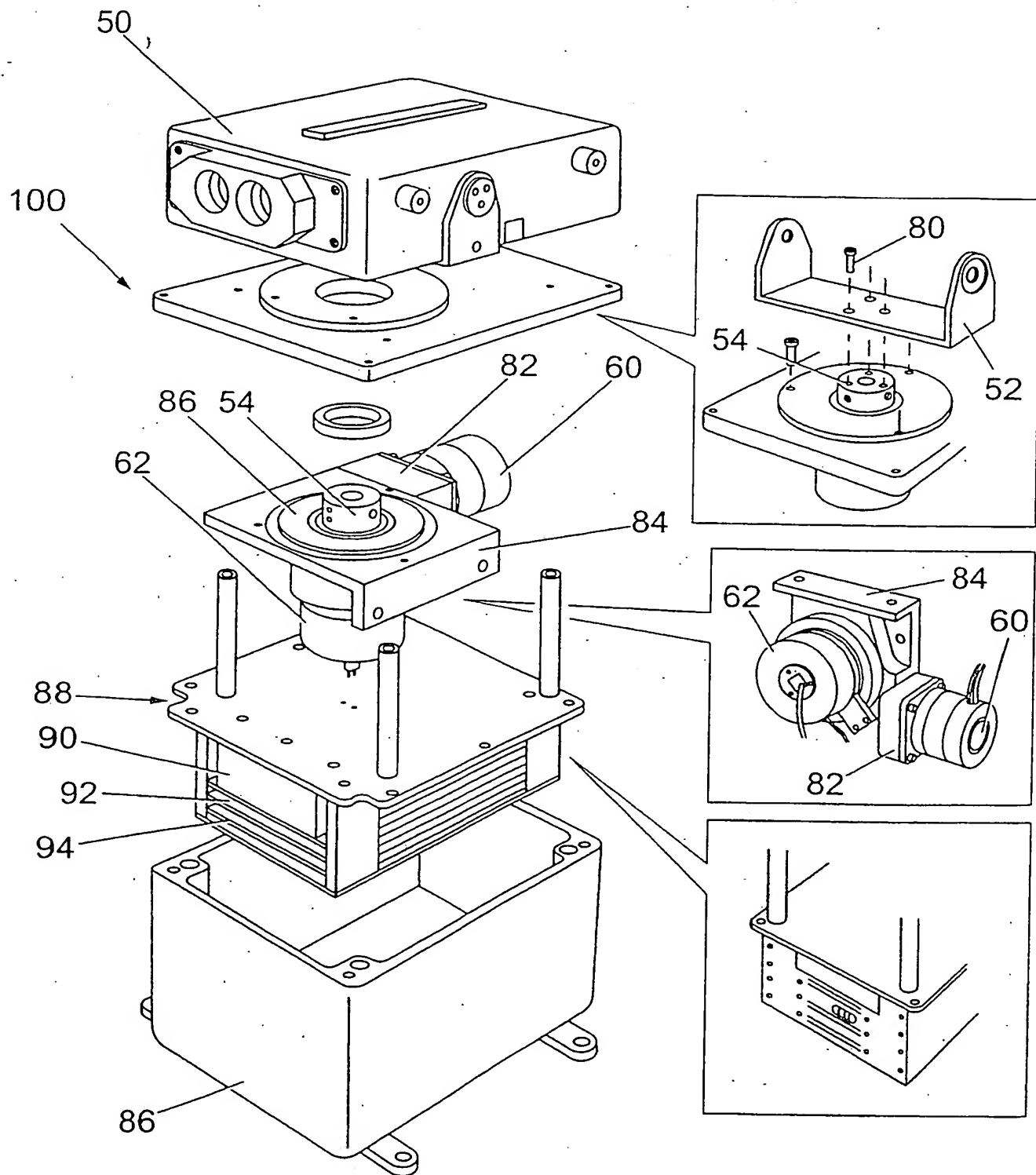


Fig. 3

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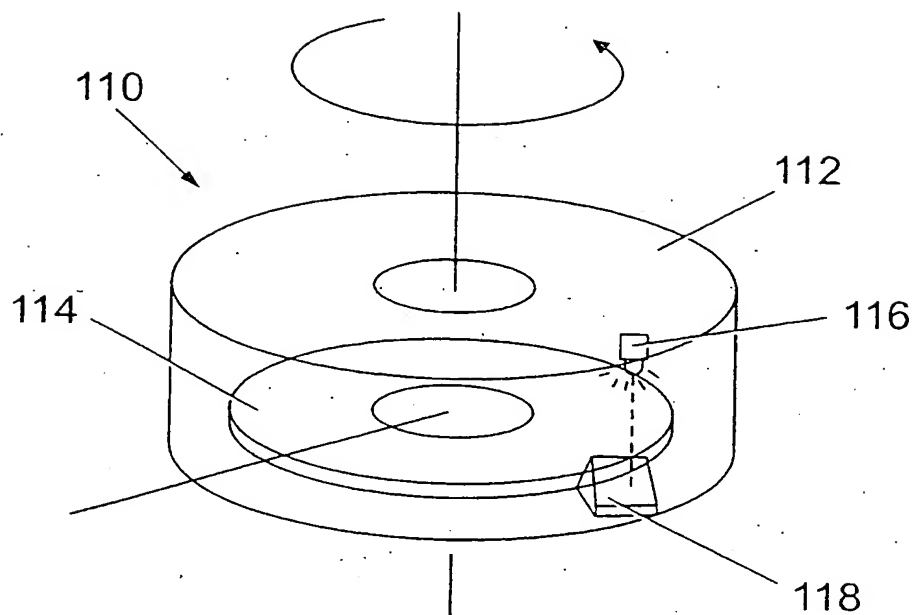


Fig. 4

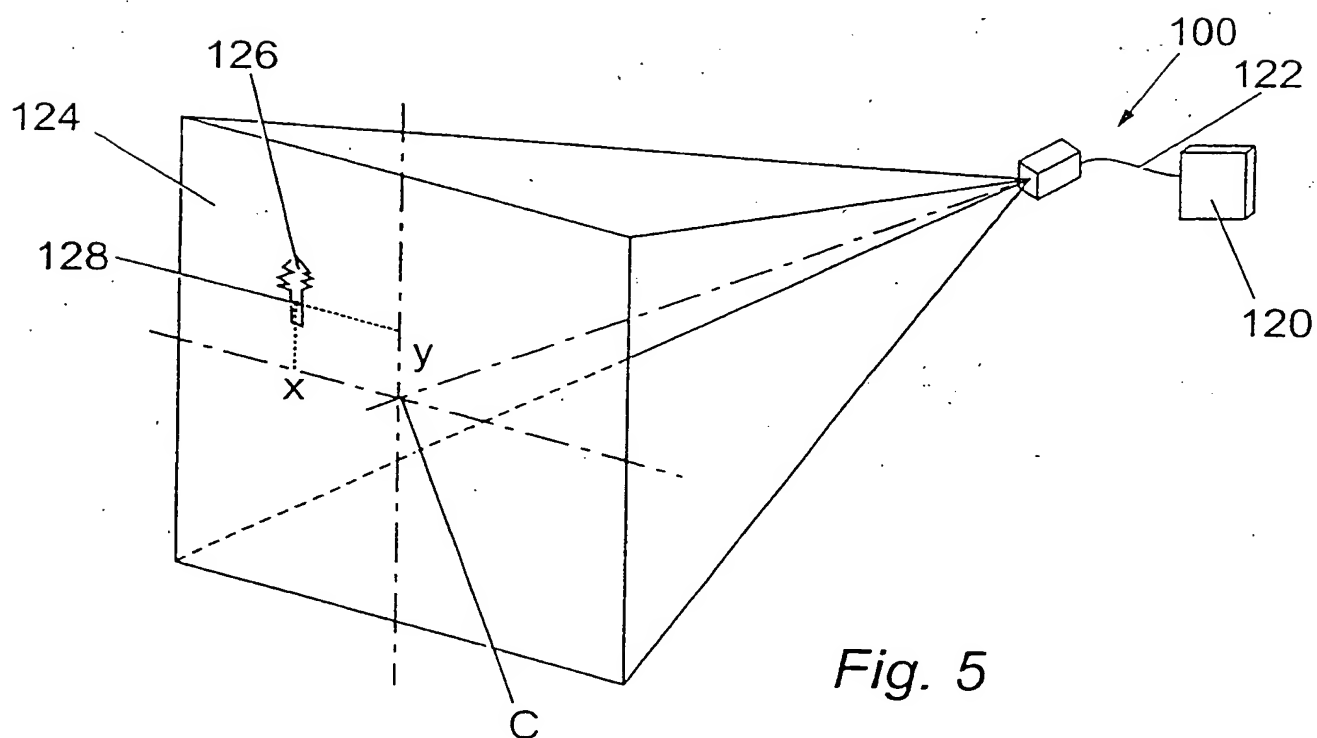
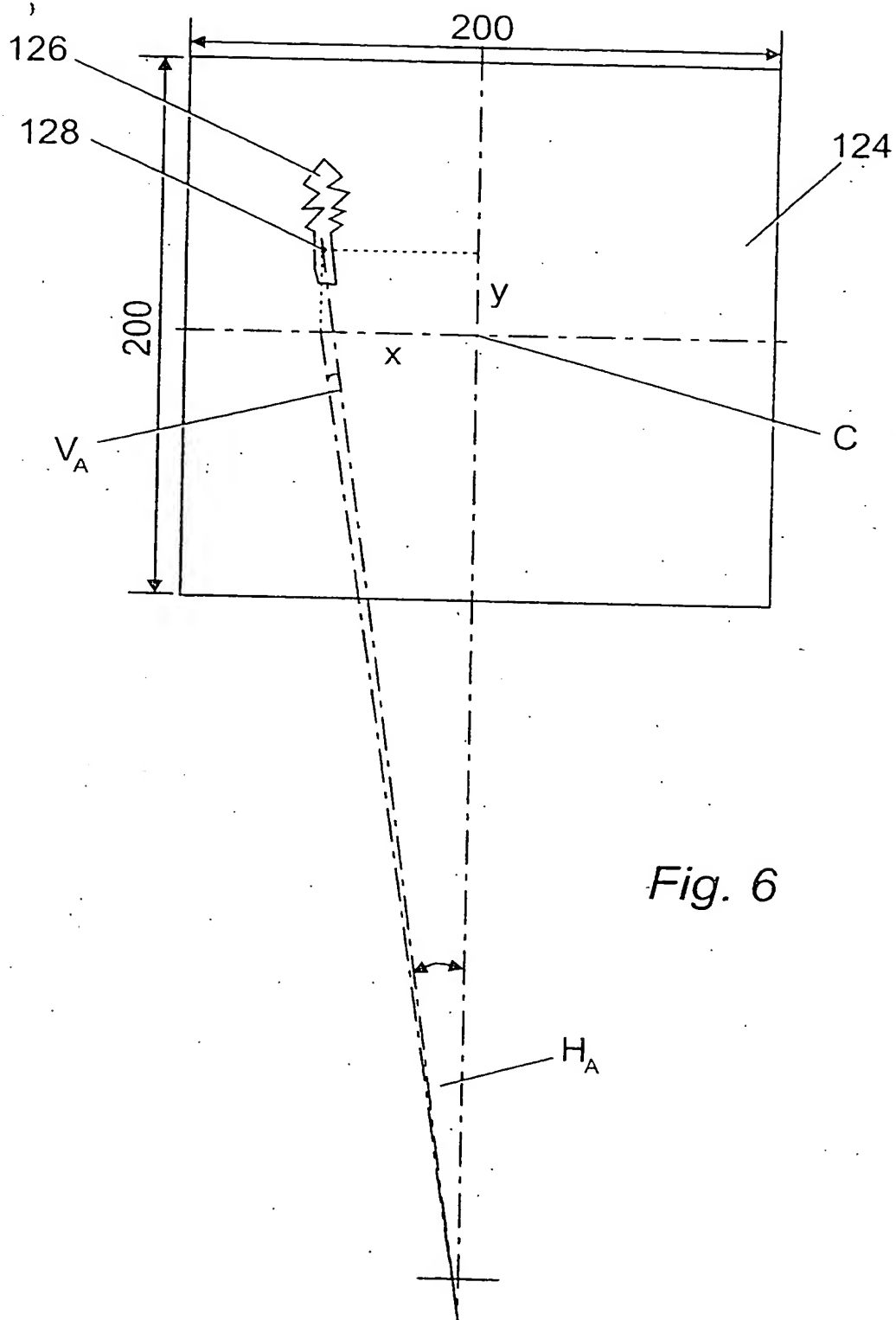


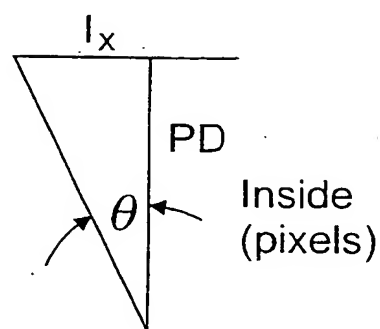
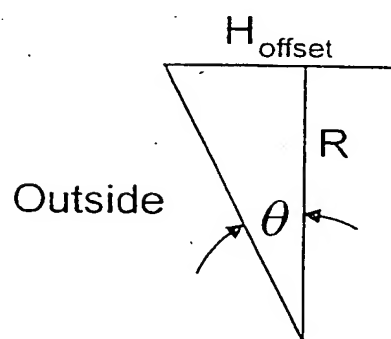
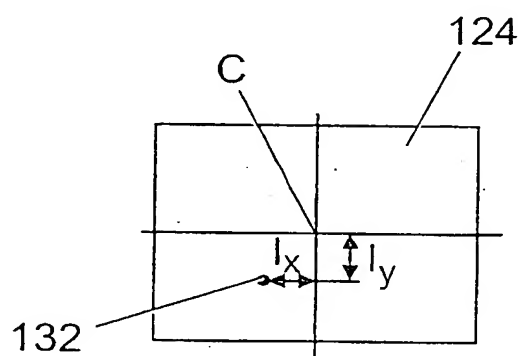
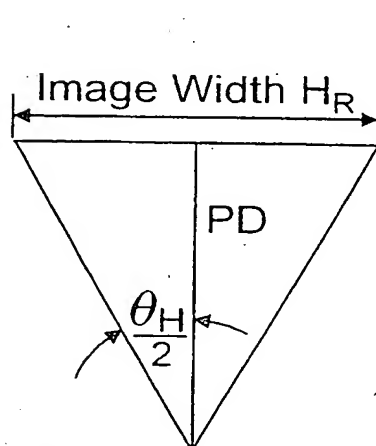
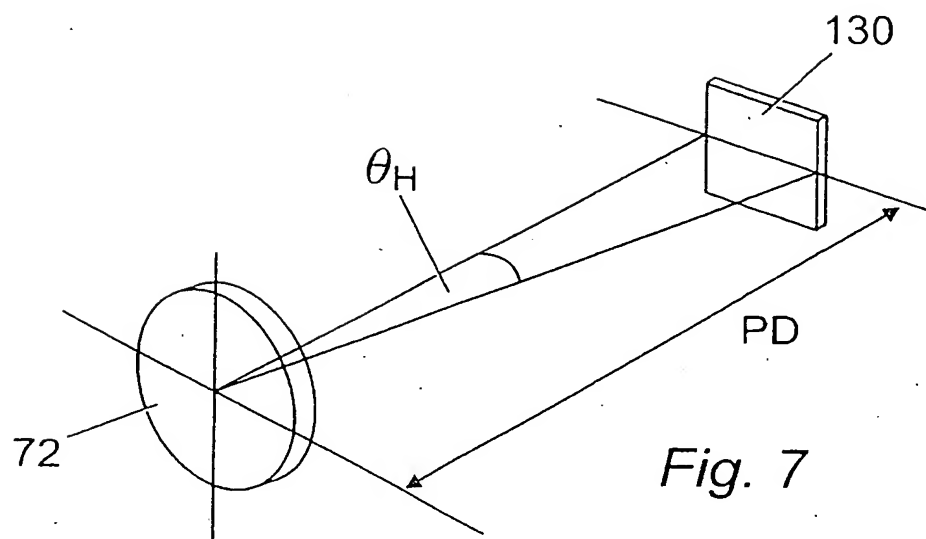
Fig. 5



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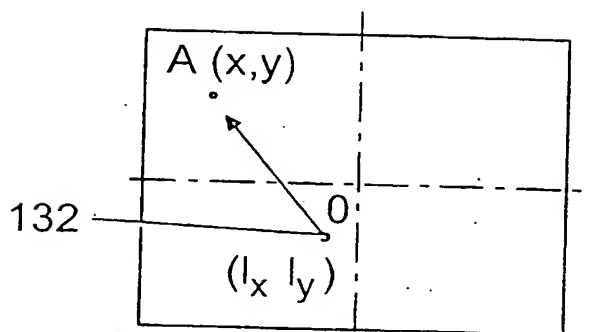


Fig. 12

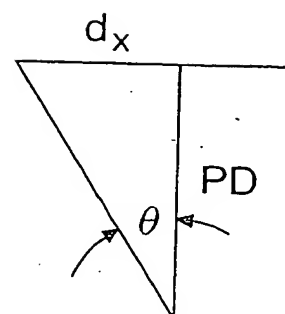


Fig. 13

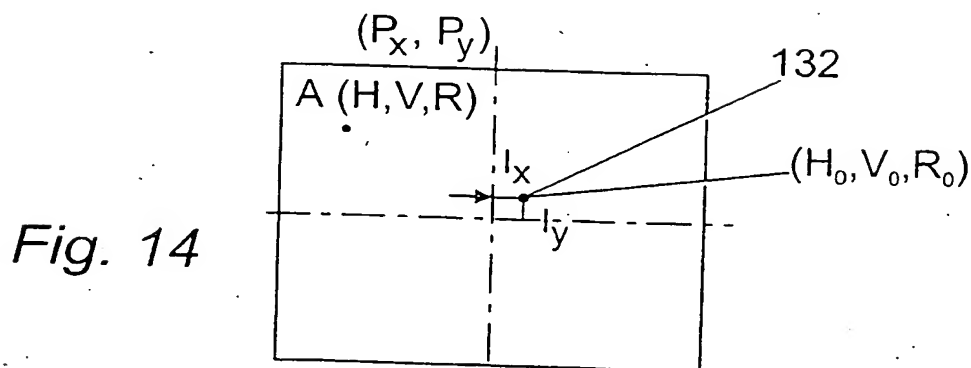


Fig. 14

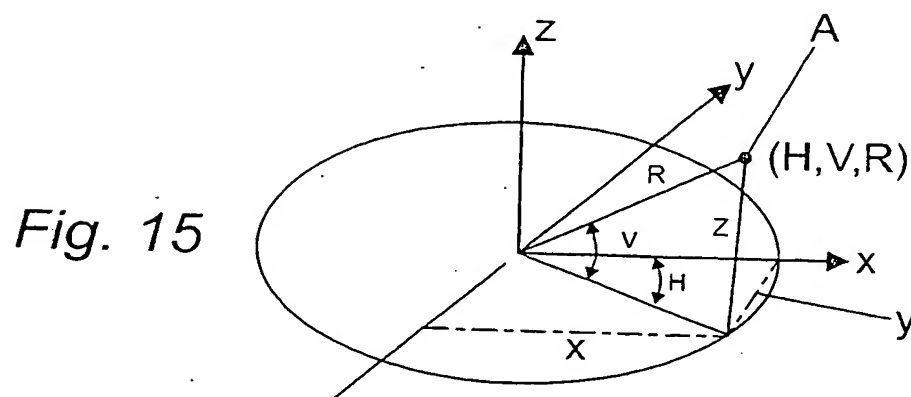
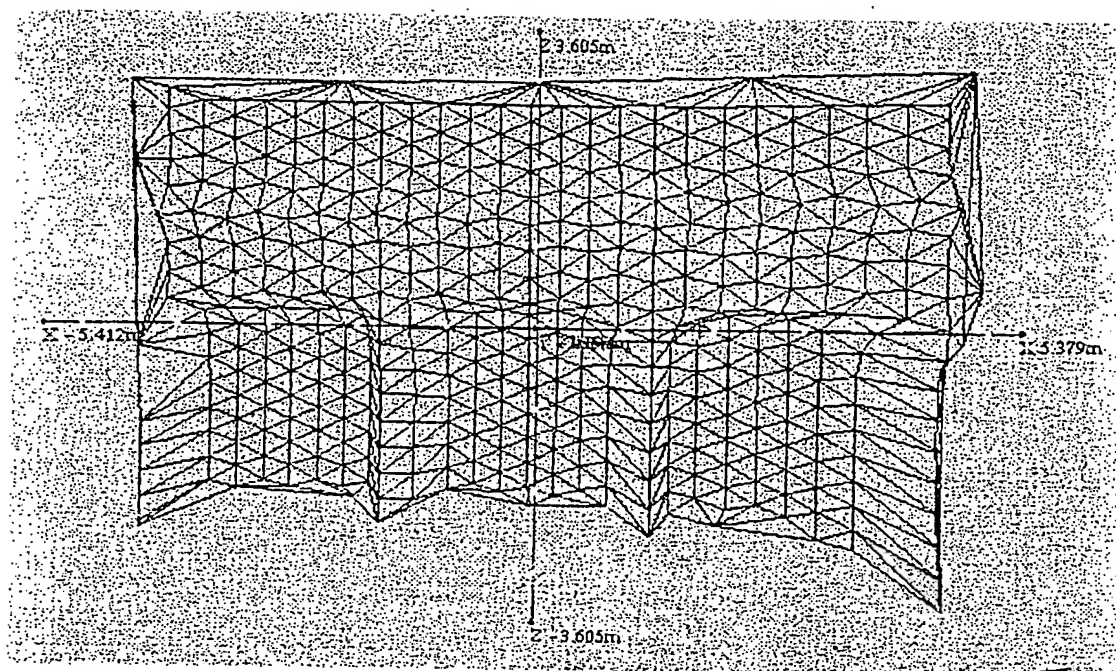


Fig. 15

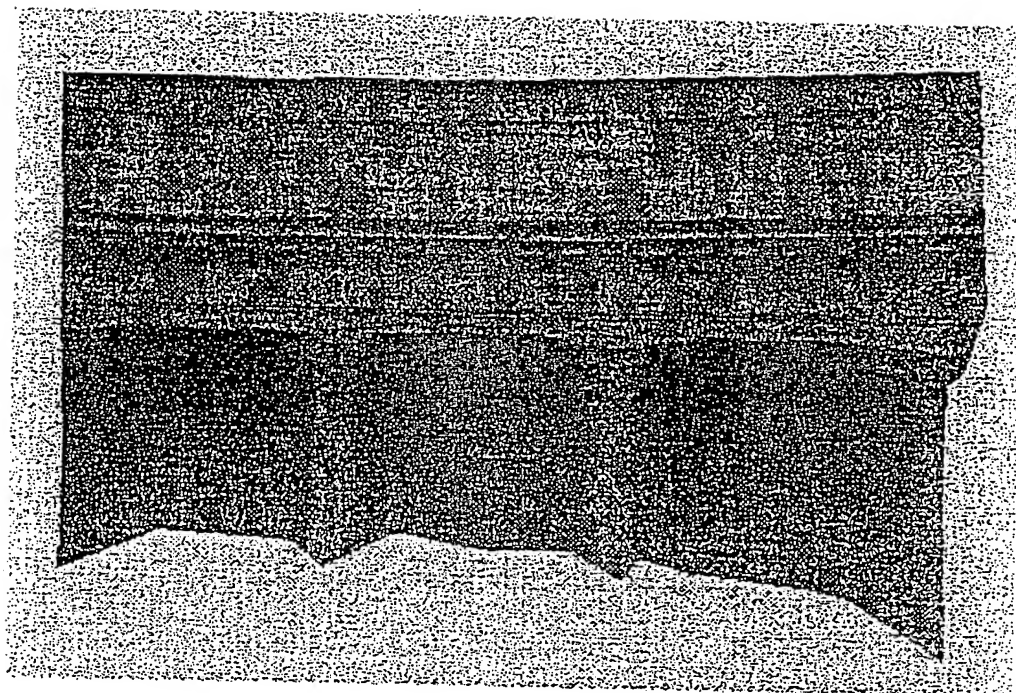
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Fig. 16

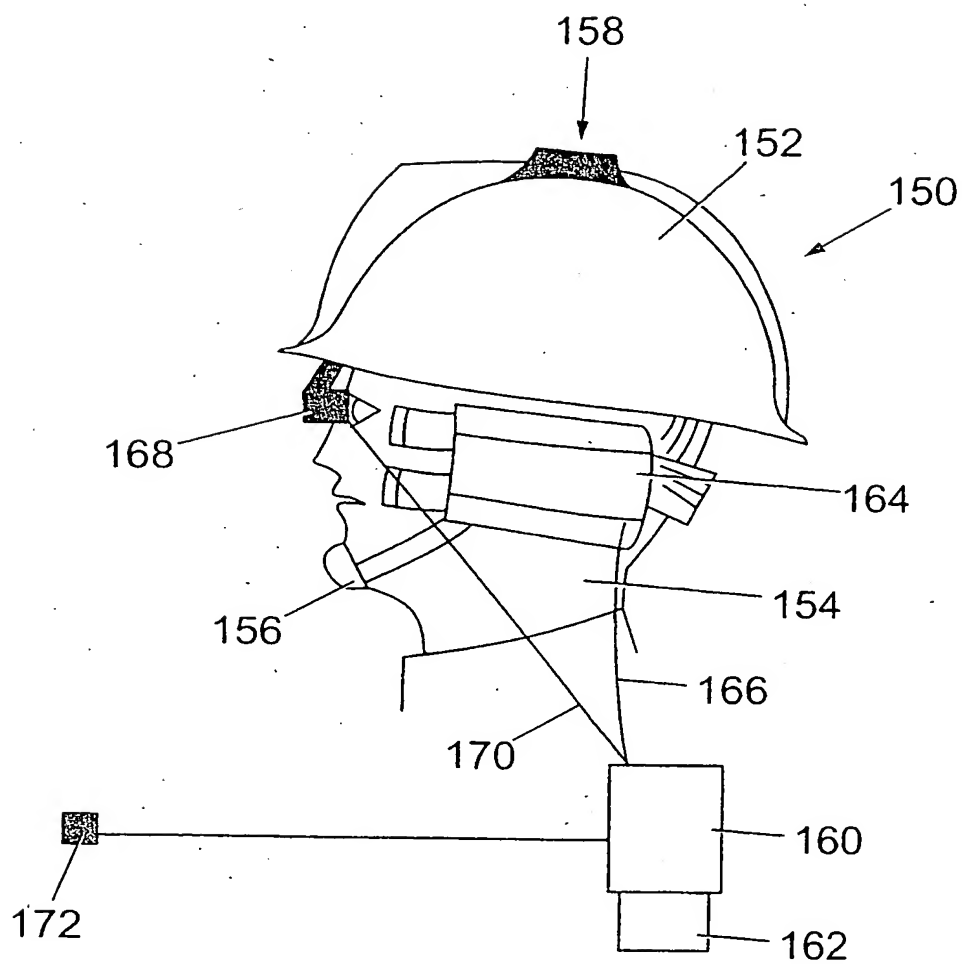
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*Fig. 17*

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*Fig. 18*

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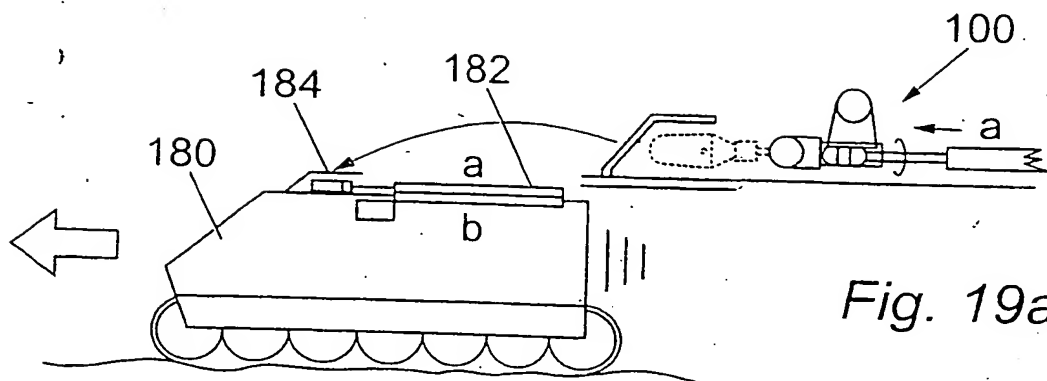


Fig. 19a

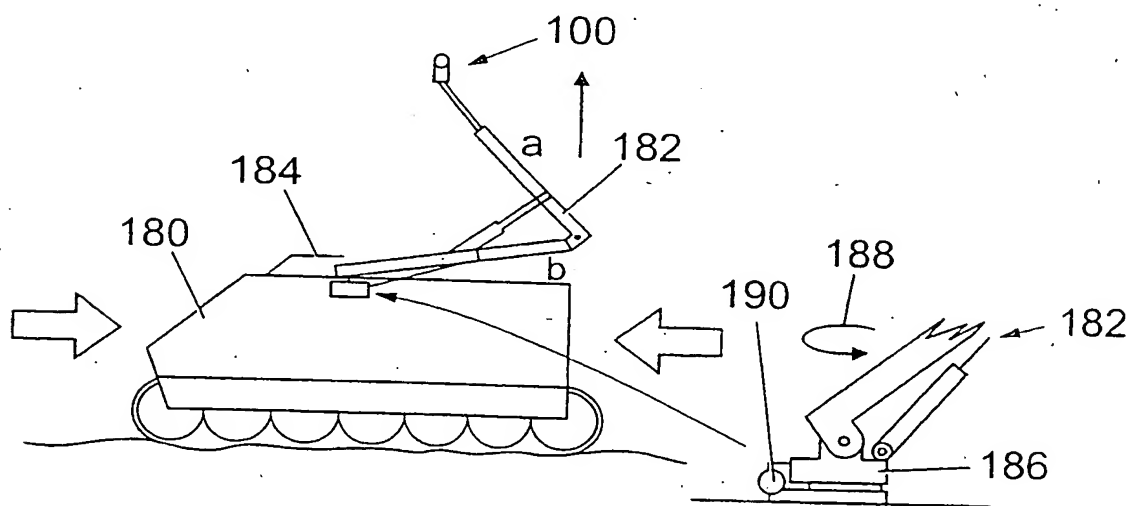


Fig. 19b

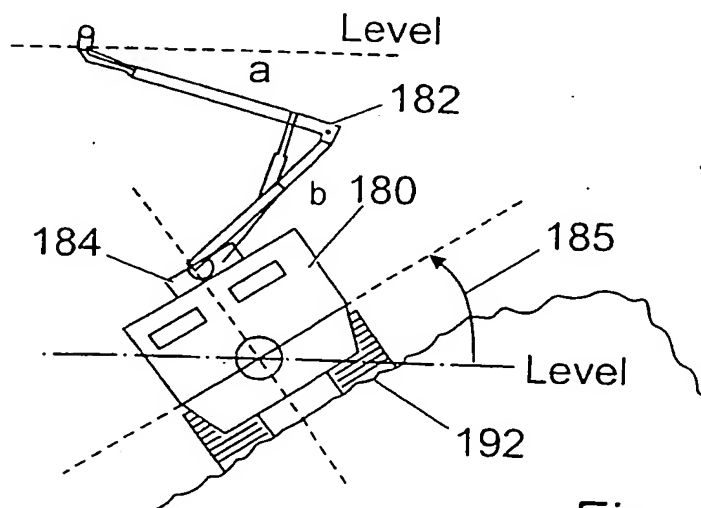


Fig. 19c

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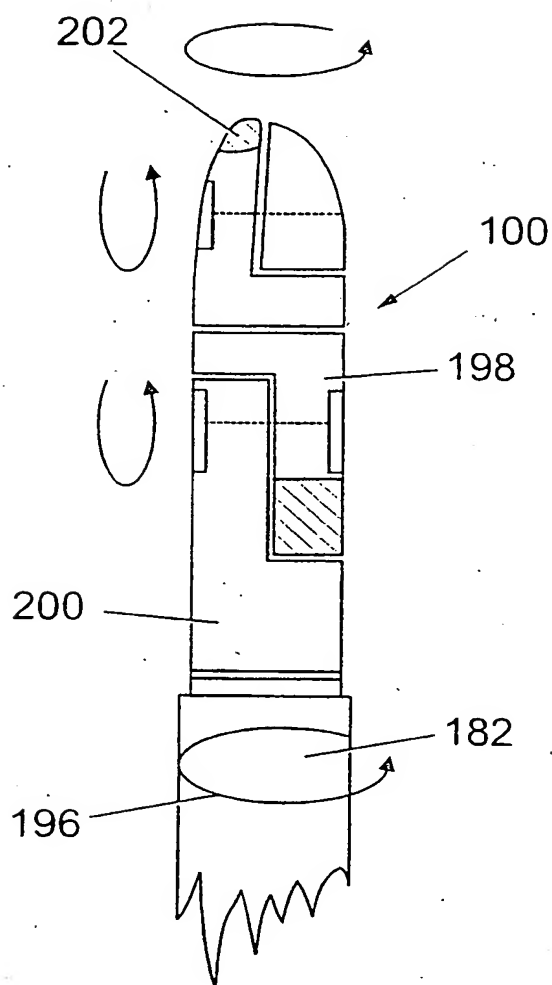


Fig. 20a

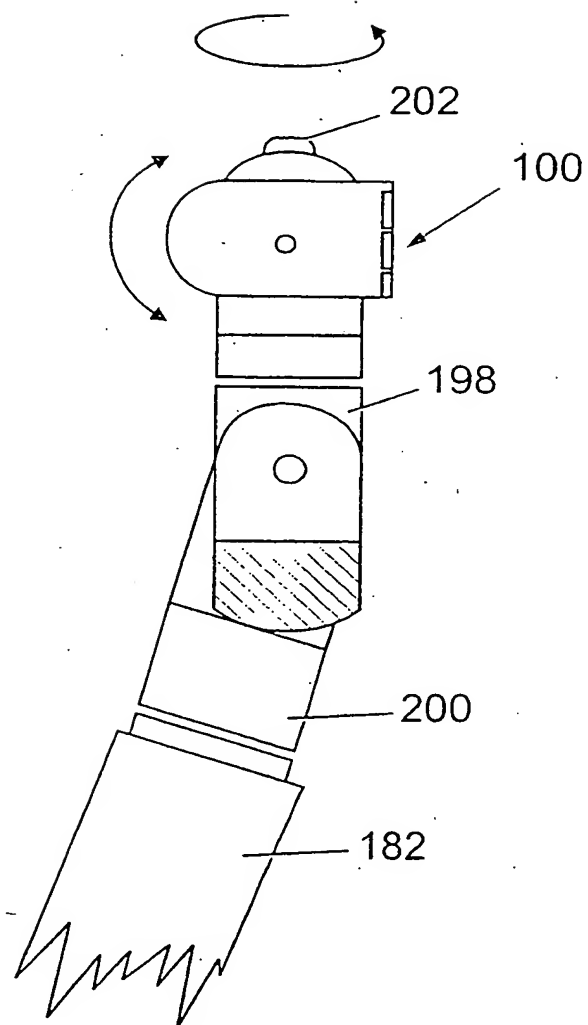
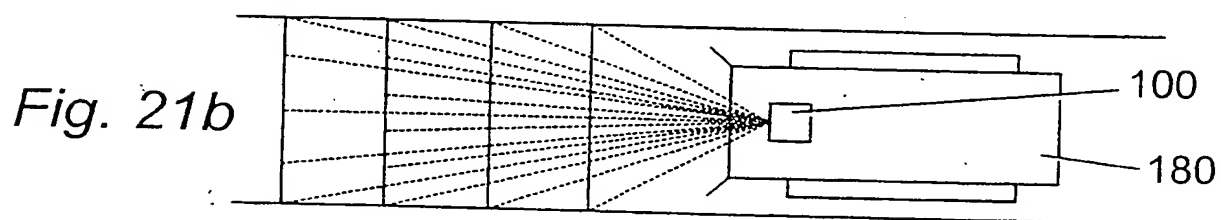
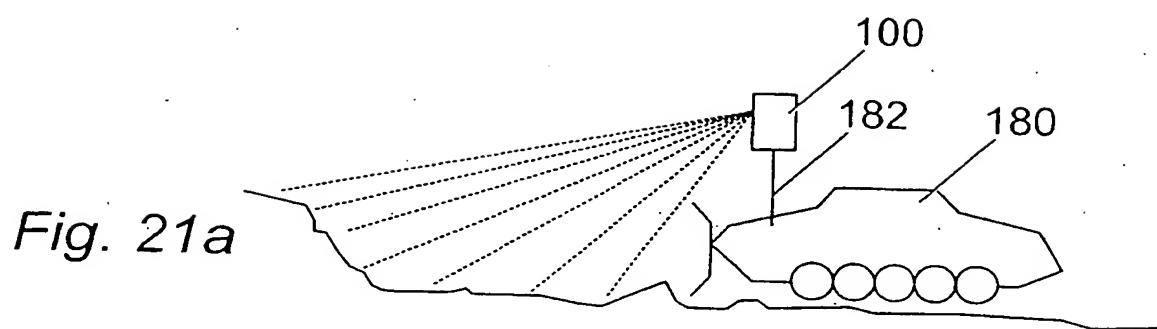


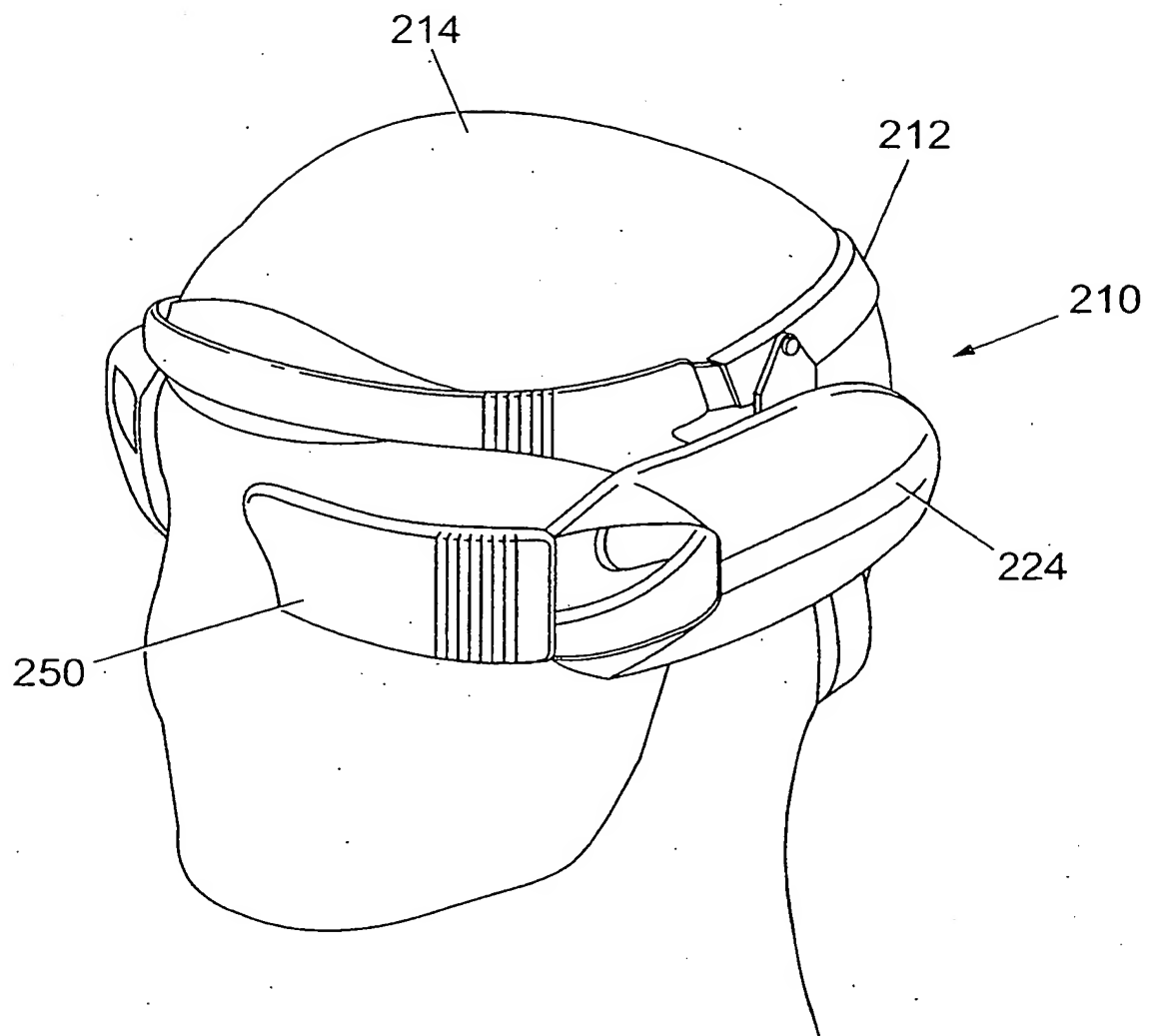
Fig. 20b



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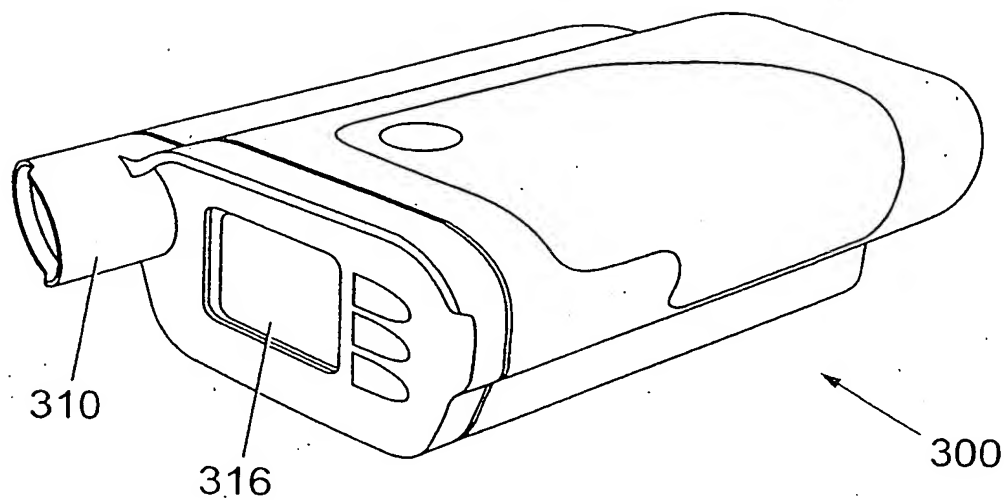


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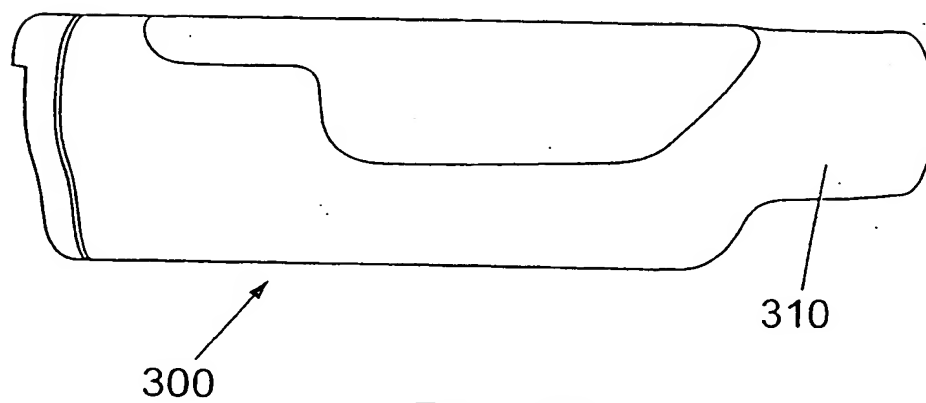


*Fig. 22*

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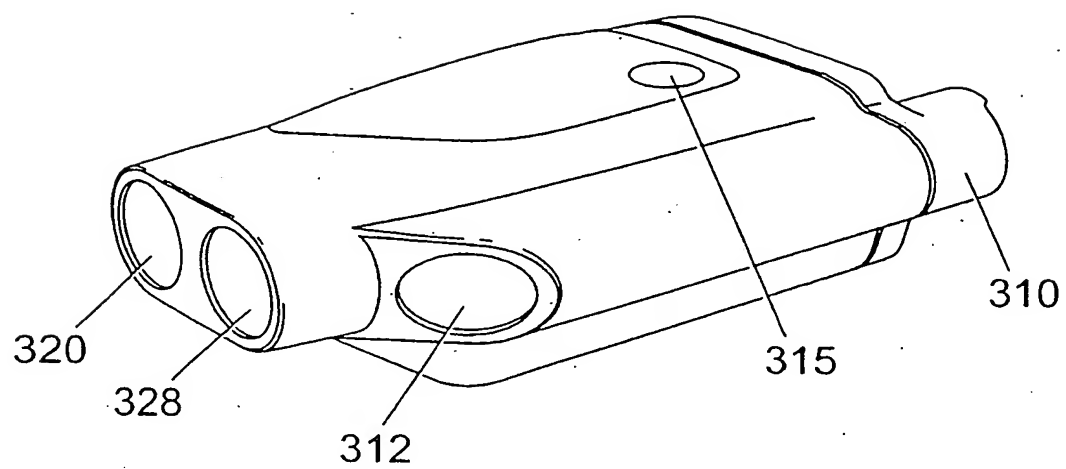


*Fig. 23*

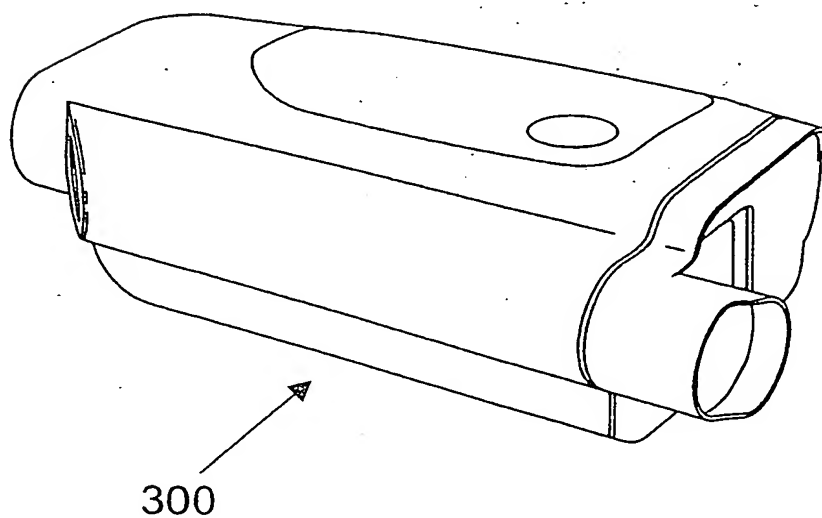


*Fig. 24*

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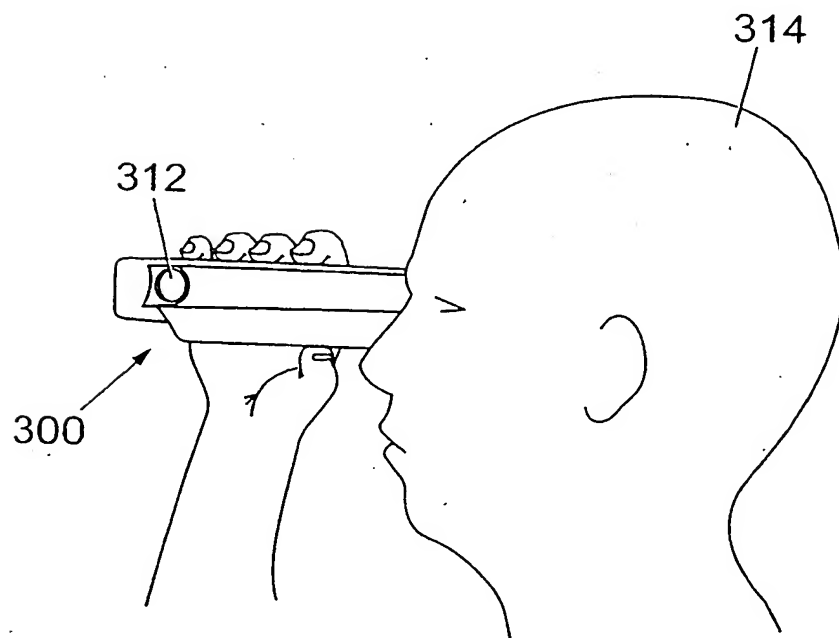
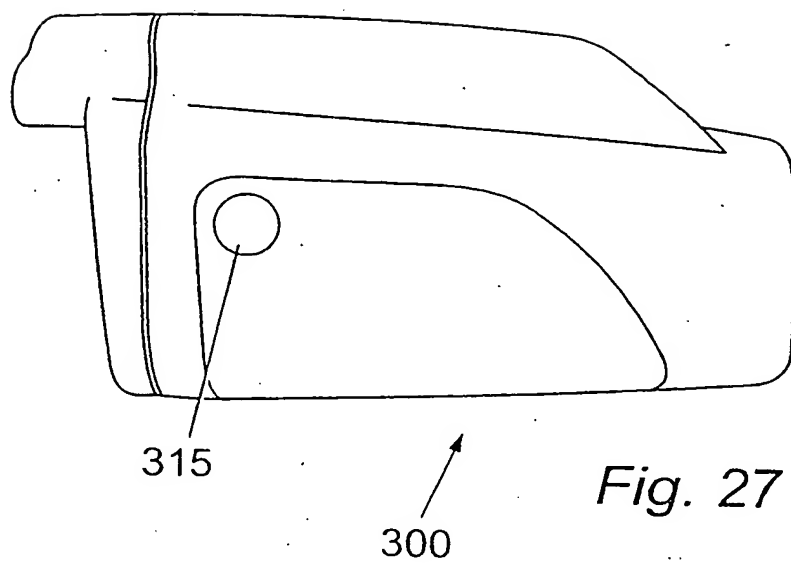


*Fig. 25*

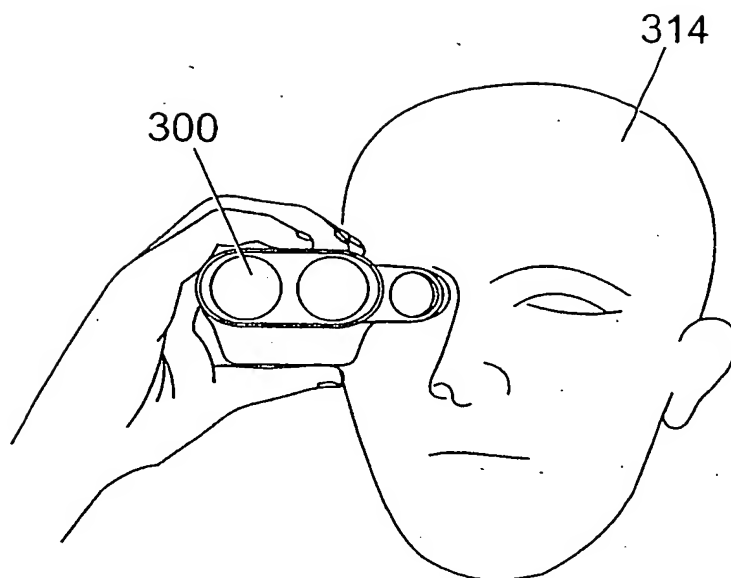


*Fig. 26*

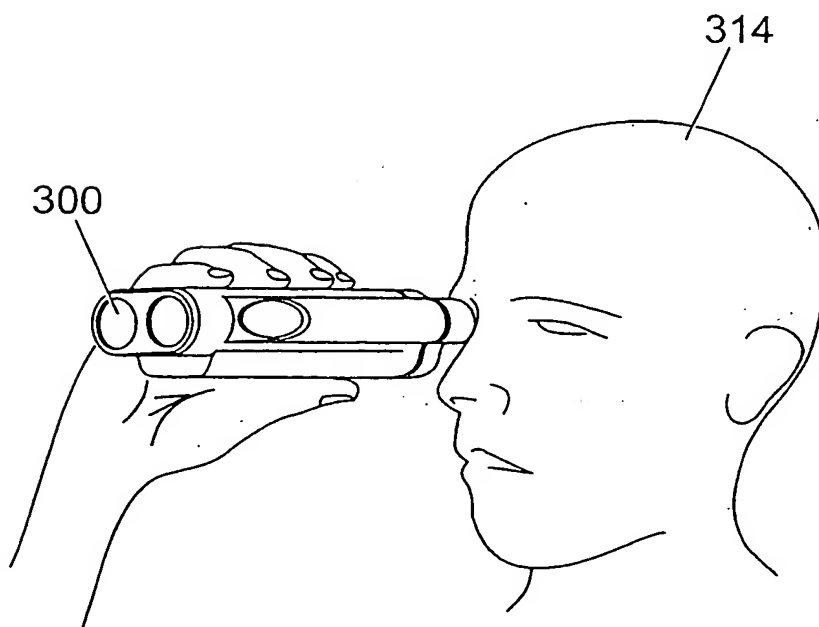
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*Fig. 28*

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*Fig. 29*



*Fig. 30*

# INTERNATIONAL SEARCH REPORT

International Application No.  
PCT/GB 99/03518

L. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 G01C15/00 G01S17/89

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 G01S G01C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 481 278 A (PIETZSCH IBP GMBH) 22 April 1992 (1992-04-22)	1,2, 4-10,14, 15,20-22 16-18
Y	the whole document	
X	WO 98 43113 A (UTEDA DR NIEBUHR GMBH ;NIEBUHR ERIK (DE)) 1 October 1998 (1998-10-01) the whole document	1-3, 6-15, 20-22
X	WO 97 40342 A (CYRA TECHNOLOGIES INC ;KACYRA BEN K (US); DIMSDALE JERRY (US); BRU) 30 October 1997 (1997-10-30) the whole document	1-15, 19-21 22
Y	WO 98 10246 A (UNIV FLORIDA) 12 March 1998 (1998-03-12) abstract	16-18

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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